

# Effects of an Intubating Dose of Succinylcholine and Rocuronium on the Larynx and Diaphragm

## An Electromyographic Study in Humans

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**Background:** Paralysis of the vocal cords is one objective of using relaxants to facilitate tracheal intubation. This study compares the neuromuscular blocking effect of succinylcholine and rocuronium on the larynx, the diaphragm, and the adductor pollicis muscle.

**Methods:** Electromyographic response was used to compare the neuromuscular blocking effect of succinylcholine and rocuronium on the laryngeal adductor muscles, the diaphragm, and the adductor pollicis muscle. Sixteen patients undergoing elective surgery were anesthetized with propofol and fentanyl, and their tracheas were intubated without neuromuscular blocking agents. The recurrent laryngeal and phrenic nerves were stimulated at the neck. The electromyographic response was recorded from electrodes placed on the endotracheal tube and intercostally before and after administration of 1 mg/kg succinylcholine or 0.6 mg/kg rocuronium.

**Results:** The maximum effect was greater at the adductor pollicis (100 and 99%) than at the larynx (96 and 97%) and the diaphragm (94 and 96%) after administration of succinylcholine and rocuronium, respectively ( $P \leq 0.05$ ). Onset time was not different between the larynx ( $58 \pm 10$  s), the diaphragm ( $57 \pm 8$  s), and the adductor pollicis ( $54 \pm 13$  s), after succinylcholine (all mean  $\pm$  SD). After rocuronium, onset time was  $124 \pm 39$  s at the larynx,  $130 \pm 44$  s at the diaphragm, and  $115 \pm 21$  s at the adductor pollicis. After succinylcholine administration, time to 90% recovery was  $8.3 \pm 3.2$ ,  $7.2 \pm 3.5$ , and  $9.1 \pm 3.0$  min at the larynx, the diaphragm, and the adductor pollicis, respectively. Time to 90% recovery after rocuronium administration was  $34.9 \pm 7.6$ ,  $30.4 \pm 4.2$ , and  $49.1 \pm 11.4$  min at the larynx, the diaphragm, and the adductor pollicis, respectively.

**Conclusion:** Neuromuscular blocking effect of muscle relaxants on the larynx can be measured noninvasively by electro-

myography. Although the larynx appears to be resistant to muscle relaxants, we could not demonstrate that its onset time differed from that of peripheral muscles. (Key words: Neuromuscular relaxants; respiratory muscles; tracheal intubation.)

VOCAL cord paralysis is one objective of using neuromuscular blocking agents (NMBAs) to facilitate tracheal intubation. Complete relaxation of the laryngeal adductor muscles and the diaphragm is necessary to achieve good intubating conditions. An ideal NMBA to facilitate tracheal intubation would provide rapid onset and a short but profound effect, followed by rapid spontaneous recovery of neuromuscular function.<sup>1</sup> Such properties are important in safe airway management during anesthesia, so tracheal intubation can be performed promptly and muscle power can recover rapidly to allow airway protection at the end of anesthesia. The time course and potency of muscle relaxants differ at laryngeal muscles and the diaphragm, as compared with the adductor pollicis.<sup>2-9</sup> However, no study compared simultaneously the effect of muscle relaxants at these muscles. In the current study, we developed a noninvasive electromyographic method of assessment of the neuromuscular blockade at the laryngeal adductor muscles. Because succinylcholine and rocuronium are the NMBAs for which the pharmacodynamic profiles are particularly favorable for achieving rapid satisfactory intubation conditions, we studied and compared their action on laryngeal, diaphragm, and adductor pollicis muscles using evoked electromyographic activity.

## Methods

After Institutional Review Board approval and informed consent, 16 unpremedicated patients, ASA physical status I or II, between 38–61 yr of age, undergoing elective orthopedic surgery during general anesthesia were studied. There were 12 men and 4 women. No patient had any history of abnormal response to NMBAs.

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### Anesthetic Management

Anesthesia was induced with 2.5 mg/kg propofol and 2 mg/kg fentanyl, and orotracheal intubation was performed 2 min later without using a muscle relaxant. Anesthesia was maintained with 60% nitrous oxide in oxygen and a continuous infusion of  $8\text{--}12\text{ mg} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$  propofol and 1 mg/kg fentanyl every 30 min. Ventilation was controlled to maintain the end-tidal carbon dioxide concentration between 3.5–4.5%. All patients were studied while in the supine position and covered with a warm heating blanket (Bair Hugger; Augustine, Eden Prairie, MN).

### Measurements

#### Nerves Stimulation

The recurrent laryngeal nerves were stimulated using surface electrodes, as described by Donati *et al.*<sup>10</sup> The negative electrode was placed on the notch of the thyroid cartilage and the positive electrode was placed on the sternum.

The right phrenic nerve was stimulated at the neck using percutaneous insulated needle electrodes placed at the inferolateral edge of the sternomastoid muscle to a depth of 1.5–3.5 cm. Proper positioning of the needle was achieved when phrenic nerve stimulation caused a hiccuping movement of the right hemidiaphragm without activation of the muscles supplied by the brachial plexus. The ulnar nerve was stimulated at the wrist using skin surface electrodes.

#### Measurements of Evoked Responses

The electromyographic activity of the laryngeal adductor muscles (La) was measured (Viking II; Nicolet, Madison, WI) using a specially designed endotracheal tube (Nim-2 endotracheal tube; Xomed, Jacksonville, FL). Two pairs of surface electrodes are situated 0.5 cm apart and laterally, 2.5 cm above the cuff of this endotracheal tube (ID, 7.5–8.5 mm) so that they are placed in contact with the vocal cords after tracheal intubation (fig. 1). After the cuff was inflated to a pressure sufficient to prevent leaks, contact between vocal cord and recording electrodes was confirmed by direct laryngoscopic visualization during recurrent laryngeal nerve stimulation and in resting conditions. To prevent pharyngolaryngeal motion, the head and the cervical spine were propped up in a neutral position, and the endotracheal tube was then fixed in the midline at the lips. The electromyographic activity of the diaphragm (Di) was measured by two silver-silver chloride surface electrodes placed 2 cm apart in either the seventh or the eighth intercostal

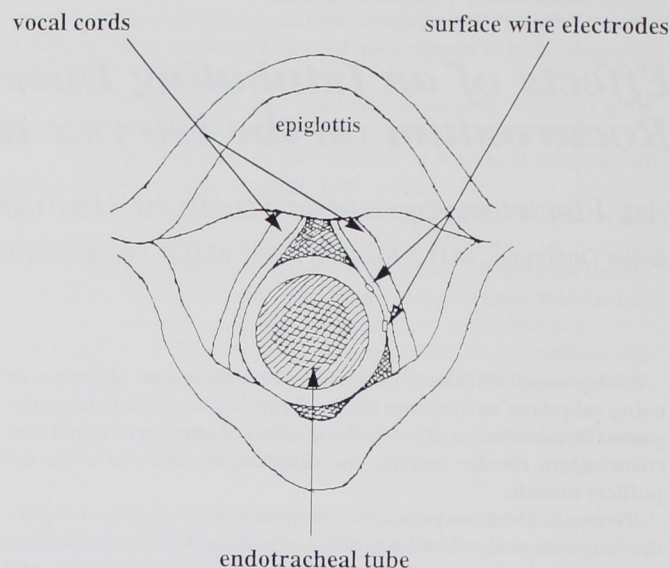


Fig. 1. Cross-section of the endotracheal tube with built-in electromyographic electrodes at the level of the vocal cords.

space between the right anterior axillary and the mid clavicular line.

The evoked response of the adductor pollicis muscle was recorded with skin surface electrodes placed in regard to the thenar muscles and by measuring the tension developed at the thumb on the same hand using a force transducer (Entran, Les Clayes sous Bois, France) with a preload of 200–500 g.

Supramaximal stimuli, defined as the current 20% above the threshold for maximal response (20–35 mA for the right phrenic nerve, 45–65 mA for the recurrent laryngeal nerves, and 60 mA for the ulnar nerve), were applied at 0.1 Hz, and the rate of mechanical ventilation was adjusted so stimuli occurred at the end of expiration. The electromyographic activity of the three muscles was amplified and simultaneously recorded with a gated electromyographic amplifier using a latency of 2 ms and a window of 10 ms for the adductor pollicis and the larynx and stored on a hard disk. The latency was 1 ms and the window was 20 ms for electromyographic registration at the diaphragm. The peak-to-peak amplitude of the compound action potential was measured.

#### Clinical Protocol

After steady response for each muscles was recorded for 3 min, a single dose of succinylcholine iodide, 1 mg/kg, or rocuronium bromide, 0.6 mg/kg, was injected intravenously over 10 s, and the evoked electromyographic responses and force of contraction of the adductor pollicis were recorded until full recovery. The fol-

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**Table 1. Onset Time and Recovery of Neuromuscular Blockade Induced by Succinylcholine or Rocuronium on the Larynx, the Diaphragm, and the Adductor Pollicis in Anesthetized Patients**

	Larynx	Diaphragm	Adductor Pollicis
Succinylcholine 1 mg · kg <sup>-1</sup> (n = 8)			
Maximum block (%)	96 ± 2 (91–100)	94 ± 4 (90–100)	100 (100–100)
Onset time (s)	58 ± 10 (45–75)	57 ± 8 (50–75)	54 ± 13 (40–75)
TH25 (min)	4.3 ± 1.6 (1.8–7.0)*	3.7 ± 1.5 (1.8–6.5)*	6.9 ± 2.6 (4.2–12.1)
TH75 (min)	7.3 ± 3.1 (5.0–13.8)	6.2 ± 3.0 (3.0–12.5)*	8.3 ± 2.9 (5.0–14.0)
TH90 (min)	8.3 ± 3.2 (5.7–14.5)	7.2 ± 3.5 (3.5–14.1)*	9.1 ± 3.0 (5.5–14.7)
Rocuronium 0.6 mg · kg <sup>-1</sup> (n = 8)			
Maximum block (%)	97 ± 3 (90–100)	96 ± 4 (90–100)	99 ± 1 (97–100)
Onset time (s)	124 ± 39 (70–175)	130 ± 44 (70–180)	115 ± 21 (100–160)
TH25 (min)	21.2 ± 5.0 (14.8–28.8)*	17.9 ± 2.1 (14.2–19.3)*	29.5 ± 8.2 (25.5–43.0)
TH75 (min)	31.0 ± 6.3 (24.5–42.1)*	27.3 ± 3.8 (24.0–32.8)*	43.6 ± 9.4 (28.5–56.0)
TH90 (min)	34.9 ± 7.6 (26.3–46.2)*	30.4 ± 4.2 (26.0–35.7)*	49.1 ± 11.4 (32.2–63.2)

Values are mean ± SD; values in parentheses are range. TH25, TH75, and TH90 are the times between injection of succinylcholine and recovery of the evoked twitch response to 25, 75, and 90% of control value.

\*  $P < 0.01$  versus adductor pollicis.

lowing measurements were obtained from the recordings of the evoked response of the three muscles: maximal depression of the evoked electromyographic control response (Emax); time between the injection of succinylcholine or rocuronium and achievement of 90% depression of the twitch response (onset time); time between muscle relaxant administration and recovery of 25, 75, and 90% of control responses (TH25, TH75, TH90).

#### Statistical Analysis

The results are presented as the mean ± SD and extreme values. Comparison of the incidence of 100% blocking effect between the muscle groups was performed by chi-square test. Results were compared using repeated-measures analysis of variance followed by the Student *t* test corrected for the number of comparisons.

### Results

Succinylcholine caused a 100% block at the adductor pollicis in all patients, whereas it was  $96 \pm 2\%$  at the larynx and  $94 \pm 4\%$  at the diaphragm (table 1). After succinylcholine, a 100% block was observed in eight patients at the adductor pollicis versus in three patients at the larynx and in two patients at the diaphragm ( $P < 0.05$ ). The onset time of succinylcholine did not differ between the three muscles studied. TH25 at the larynx was  $4.3 \pm 1.6$  min and was shorter ( $P < 0.01$ ) than at the adductor pollicis ( $6.9 \pm 2.6$  min). TH75 and TH90 were not different between the larynx and the adductor pollicis. TH25, TH75, and TH90 were all shorter at the

diaphragm than at the adductor pollicis. After succinylcholine, a linear correlation close to identity was observed between the mechanical and electromyographic response of the adductor pollicis during onset (mechanical TH (%) = 0.99 electromyographic TH (%) + 3.2%;  $r = 0.98$ ) and offset (mechanical TH (%) = 0.99 electromyographic TH (%) + 3.4%;  $r = 0.98$ ) of paralysis. Emax of rocuronium at the larynx was  $97 \pm 3\%$ , at the diaphragm was  $96 \pm 4\%$ , and at the adductor pollicis was  $99 \pm 1\%$ . After rocuronium, a 100% blocking effect was observed in six patients at the adductor pollicis versus in two patients at the larynx and the diaphragm ( $P < 0.05$ ). Onset time of rocuronium did not differ significantly between the three muscles studied. Recovery from neuromuscular blockade induced by rocuronium was always shorter at the larynx and the diaphragm than at the adductor pollicis. TH25, TH75 and TH90 were all significantly shorter at the two respiratory muscles than at the adductor pollicis. After rocuronium a linear correlation was observed between the mechanical and the electromyographic response of the adductor pollicis during onset [mechanical TH (%) = 1.05 electromyographic TH (%) - 2.1%;  $r = 0.93$ ] and offset [mechanical TH (%) = 1.18 electromyographic TH (%) - 3.7%;  $r = 0.96$ ] of paralysis.

### Discussion

We described an electromyographic method for measurement of the effect of muscle relaxants on the function of laryngeal adductor muscles. In this study, the onset and offset of neuromuscular block of the laryngeal

adductor muscle after intubating doses of succinylcholine (1 mg/kg) and rocuronium (0.6 mg/kg) were measured by electromyography. The evoked electromyographic responses of the larynx was compared to that of the diaphragm and the adductor pollicis.

We used the evoked electromyographic responses to measure the neuromuscular blocking effect of succinylcholine and rocuronium at the laryngeal muscles because it is a noninvasive method. In comparison, the measure of adduction force of the vocal cords by positioning the balloon of the endotracheal tube between the vocal cords and measuring the pressure generated in the balloon after stimulation of the recurrent laryngeal nerve is much more critical.<sup>10</sup> Although accurate, this technique allowed an assessment of function of the vocal cords over a period of time not in excess of 23 min<sup>10</sup> and is at risk of tracheal extubation. By measuring the compound electromyographic of the laryngeal muscles with surface electrodes, it is possible that activity from other muscles could have caused interference. The electrodes placed on the laryngeal portion of the endotracheal tube record the activity of thyroarytenoid muscles,<sup>11</sup> which are the major laryngeal adductors.<sup>12</sup> Other laryngeal muscles, such as the posterior cricoarytenoid, the lateral cricoarytenoid, and the cricothyroid muscles, are more distant from the recording electrodes. Because the voltage detected from active muscles is attenuated by an inverse square relation with distance, the contribution to our recording, of muscles other than the thyroarytenoid muscles, is likely to be very small, but cannot be entirely discounted.

Paralysis-induced changes in the position of the larynx<sup>13</sup> could alter the electromyographic recordings. The length of our laryngeal electromyographic recording electrodes (1.25 cm) near the muscles of the vocal cords would permit displacement of laryngeal position without changes in measured electromyographic recording. In the current study, the diaphragmatic evoked response was measured by electromyography, as previously described.<sup>14</sup> Measures of the evoked transdiaphragmatic pressure have also been used to evaluate the effect of muscle relaxants on the diaphragm; however, this technique is more difficult to apply, mainly because it requires bilateral phrenic nerve stimulation throughout the study.<sup>15-17</sup>

In the current study, we observed that the evoked response of the adductor pollicis measured by electromyography and by a force transducer were linearly correlated, both during onset of offset of paralysis induced by succinylcholine or rocuronium. A linear relation was

also observed by Kopman<sup>18</sup> between the electromyographic and the mechanical responses after atracurium administration in humans. However, it was claimed that the linear relation did not apply to succinylcholine because, during recovery from succinylcholine-induced neuromuscular blockade, mechanical response of the adductor pollicis returned to a greater value than the control when electromyography was still depressed.<sup>19-21</sup>

In this study, 1 mg/kg succinylcholine resulted in a similar pattern of onset of paralysis between the laryngeal adductor muscles and the diaphragm. However, most of the patients studied had an incomplete block of evoked electromyographic responses at both the diaphragm and the laryngeal muscles, which confirms the lower susceptibility of these muscles to succinylcholine.<sup>3,7,17</sup> In comparison, 1 mg/kg succinylcholine was also shown to abolish incompletely the evoked electromyographic response of the cricothyroid muscle in patients undergoing neck surgery for cancer.<sup>22</sup> Our observations of the effects of succinylcholine on the laryngeal muscles differ from those of Meistelman *et al.*,<sup>7</sup> and Wright *et al.*,<sup>22</sup> who found that in adults the onset time of succinylcholine-induced blockade was shorter at the laryngeal muscles than at the adductor pollicis. In both these studies, the evoked responses of the larynx and the adductor pollicis were measured by mechanography.<sup>7,23</sup>

The faster recovery of the diaphragm and the laryngeal muscles than the adductor pollicis after an intubating dose of succinylcholine that we observed for TH25 at least has also been reported previously.<sup>16,23</sup> TH90 of the diaphragm and vocal cord adductor muscles occurred 6.5 min and 7.5 min, respectively, after succinylcholine administration. The short time course of action of succinylcholine for these important muscles involved in respiration and airway protection may become clinical if the trachea is unexpectedly impossible to intubate.<sup>24</sup>

After 0.6 mg/kg rocuronium, the degree of maximum blockade was also less at the larynx and the diaphragm than at the adductor pollicis. However, the difference, although significant, was very slight, Emax being 97% at the larynx compared to 99% at the adductor pollicis. In comparison, Meistelman *et al.*<sup>25</sup> found that Emax was 77% at the larynx *versus* 98% at the adductor pollicis after 0.5 mg/kg rocuronium. Using the same methodology as Meistelman *et al.*,<sup>25</sup> Wright *et al.*<sup>23</sup> observed that Emax was 70 and 93% at the larynx and 99 and 100% at the adductor pollicis after 0.4 and 0.8 mg/kg rocuronium, respectively.

In the current study, onset time of rocuronium at the adductor pollicis did not differ from the value observed

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at the two other muscles, whereas Meistelman *et al.*<sup>25</sup> observed a shorter onset time at the larynx than at the adductor pollicis after rocuronium administration. In the study of Wright *et al.*,<sup>23</sup> onset time at the larynx was shorter than at the adductor pollicis after 0.4 mg/kg rocuronium, but did not diminish after 0.8 mg/kg rocuronium. Therefore, our results confirm the previous findings of the resistance and the more rapid recovery of the larynx than the adductor pollicis after rocuronium administration.<sup>23,25</sup>

In summary, the results of this investigation showed that the evoked electromyographic method can be used to measure noninvasively the response of laryngeal muscles to NMBAs. Our results confirm that the laryngeal adductor muscles are resistant to the paralyzing effects of succinylcholine and that after rocuronium administration the diaphragm and the laryngeal muscles have similar recovery patterns.

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