Comparison of succinylcholine with two doses of rocuronium using a new method of monitoring neuromuscular block at the laryngeal muscles by surface laryngeal electromyography

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We compared the onset of neuromuscular block with succinylcholine (1 mg kg⁻¹) and two doses of rocuronium (0.6 and 0.9 mg kg⁻¹) at the adductor pollicis muscle using electromyography (EMG) and acceleromyography (AMG), and at the adductor laryngeal muscles with a new electromyographic method using a disposable surface electrode attached to the cuff of a tracheal tube. At the larynx, the mean (±SD) time to 90% block and the onset time of succinylcholine (38±15 and 47±19 s, respectively) were significantly shorter (P<0.01) than for rocuronium 0.6 mg kg⁻¹ (92±42 and 106±38 s) and rocuronium 0.9 mg kg⁻¹ (52±31 and 64±30 s). We found that, with comparable degrees of neuromuscular block, the onset time of succinylcholine at the adductor pollicis was significantly shorter (P<0.01) than for rocuronium 0.6 mg kg⁻¹ and 0.9 mg kg⁻¹ (EMG, 80±39 vs 145±48 s and 99±31 s; AMG, 90±39 vs 124±53 s and 106±38 s). Clinical duration at the adductor pollicis (AMG) was significantly longer (P<0.01) for both rocuronium groups than for succinylcholine (T₄=T₁=0.7, 54±18 and 77±21 vs 8±6 min). The surface laryngeal electrode proved non-invasive, easy to use and reliable in measuring onset of the neuromuscular block at the larynx.

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Since its introduction in 1956, succinylcholine has been the main neuromuscular blocking drug for rapid-sequence induction (RSI) or difficult intubation.1 Because of its potential to cause serious side effects, efforts have been undertaken to find an alternative non-depolarizing neuromuscular blocking drug with a short onset and offset of block to replace succinylcholine, especially for RSI.2,3

Rocuronium has been studied as an alternative to succinylcholine; in most studies, however, the onset and offset of the neuromuscular block have been measured at peripheral, easily accessible muscles. Neuromuscular blockade at the larynx should be compared with peripheral muscles, such as the adductor pollicis muscle, using similar monitoring methods, such as surface electromyography.

For more than two decades, intraoperative monitoring of the recurrent laryngeal nerve has been the focus of extensive research in otolaryngological surgery of the thyroid gland. Initially, needle electrodes were used, placed translaryngeally through the operating site;4 later, needle electrodes were applied endoscopically.5 Although electromyographic signals obtained via needle electrodes are regarded as the gold standard in monitoring, special expertise is required during insertion and electrodes are needed which are not displaced during surgery.5

Recently, non-invasive forms of monitoring the laryngeal response to stimulation of the recurrent laryngeal nerve have been tested. Special tracheal tubes with integrated electrodes proved reliable but expensive,6 and a postcricoïd electrode inserted into the upper pharynx lacked reliability.6

We used a new disposable surface electrode,7 attached to a tracheal tube and placed between the vocal cords at intubation, to measure the onset of neuromuscular block obtained with two doses of rocuronium compared with succinylcholine.

Materials and methods

After approval of the local ethics committee and written informed consent had been obtained, 90 patients undergoing surgery of the thyroid gland were included in the study. Pregnant women, patients with neuromuscular, hepatic or renal disease, and patients receiving medication known to interact with neuromuscular blocking drugs were excluded.
Electrode was placed between the vocal cords for optimal electromyography (EMG) recording. The recurrent laryngeal nerve function of all patients was checked 3 days after operation using indirect laryngoscopy by the otolaryngologist. Any lesion or damage to the vocal cords due to the surface laryngeal electrode was noted.

Anaesthesia was maintained by target-controlled infusion of propofol (target concentration 3 μg ml⁻¹) and remifentanil 0.25 μg kg⁻¹ min⁻¹; mechanical ventilation (30% oxygen in air) was adjusted to achieve an end-tidal CO₂ pressure of 26–35 mm Hg.

After induction and fixation of the tracheal tube, the recurrent laryngeal nerve was stimulated transcutaneously with an external nerve stimulator (Multiliner®, Tönies, Würzburg, Germany) at the notch of the thyroid cartilage, to produce maximum response of the adductor laryngeal muscles. The external nerve stimulator has a probe that is attached at the neck with an elastic band. It delivers a current between 0 and 70 mA. Single twitch stimuli (0.1 Hz; pulse width 0.2 ms) were applied to the left recurrent nerve to determine supramaximal stimulation, and were recorded using Multiliner® software. The current was increased to that with the maximal EMG response (<70 mA) and then increased by 10 mA to ensure supramaximal stimulation. The amplitude of the compound action potentials was measured and recorded (Fig. 2). After stimulation of the left ulnar nerve with Ag/AgCl electrodes, evoked EMG single-twitch responses (0.1 Hz; pulse width 0.2 ms) from the adductor pollicis muscle via Ag/AgCl electrodes placed over the base of the thenar area were recorded; automatic calibration of the Datex Relaxograph® NMT 100 (Datex Instrumentarium Corporation, Helsinki, Finland) was used to determine supramaximal stimulation (0–70 mA). The right thumb was equipped with an acceleromyographic (AMG) probe to record the neuromuscular response of the adductor pollicis muscle. The automatic calibration setup of the TOF-guardNMT (Organon, Helsinki, Finland) was used to determine supramaximal stimulation (single twitch, 0.1 Hz).

After no change in the neuromuscular response had been detected at all three sites for at least 10 min, the patients

Fig 1 Disposable surface laryngeal electrode. The distal electrode part is glued around the tube 2 cm above the cuff and placed between the vocal cords at intubation; the electrode is proximally secured around the tube to avoid misplacement during surgery.

Fig 2 A compound action potential of the electromyographic response of the laryngeal muscles after injection of the neuromuscular blocking drug and decrease of the neuromuscular response. Amplitude height P1–P2 was measured as the neuromuscular response (mean (SD) (range)).
Table 1 Physical characteristics (mean (SD) (range))

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yr)</th>
<th>Sex (M/F)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>ASA (1, 2, 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All groups</td>
<td>52 (15)</td>
<td>29/61</td>
<td>168 (9)</td>
<td>74 (15)</td>
<td>27/45/18</td>
</tr>
<tr>
<td>Succinylcholine 1.0 mg kg⁻¹</td>
<td>55 (14)</td>
<td>9/21</td>
<td>167 (7)</td>
<td>71 (14)</td>
<td>71/49/98</td>
</tr>
<tr>
<td>Rocuronium 0.6 mg kg⁻¹</td>
<td>50 (16)</td>
<td>6/20</td>
<td>168 (8)</td>
<td>77 (17)</td>
<td>8,18,14</td>
</tr>
<tr>
<td>Rocuronium 0.9 mg kg⁻¹</td>
<td>51 (13)</td>
<td>6/20</td>
<td>168 (10)</td>
<td>74 (14)</td>
<td>10,13,7</td>
</tr>
</tbody>
</table>

Table 2 Onset time and peak effect of neuromuscular block after succinylcholine 1 mg kg⁻¹ and rocuronium 0.6 mg kg⁻¹ or 0.9 mg kg⁻¹ at the larynx and adductor pollicis muscle. Mean (SD) (range); *P<0.01, larynx vs adductor pollicis (EMG and AMG); †P<0.01, succinylcholine vs both doses of rocuronium; ‡P<0.01, rocuronium 0.9 mg kg⁻¹ vs rocuronium 0.6 mg kg⁻¹.

<table>
<thead>
<tr>
<th></th>
<th>Succinylcholine 1 mg kg⁻¹ (n=30)</th>
<th>Rocuronium 0.6 mg kg⁻¹ (n=30)</th>
<th>Rocuronium 0.9 mg kg⁻¹ (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum block (%)</td>
<td>94 (11) (90–100)</td>
<td>95 (3) (90–100)</td>
<td>98 (5) (81–100)</td>
</tr>
<tr>
<td>Lag time (s)</td>
<td>20 (11) (10–50)*</td>
<td>22 (11) (10–50)*</td>
<td>21 (13) (10–70)*</td>
</tr>
<tr>
<td>90% block T₁/T₀ (s)</td>
<td>38 (15) (10–60)*‡</td>
<td>92 (42) (30–170)*</td>
<td>52 (31) (20–190)*‡</td>
</tr>
<tr>
<td>Onset time (s)</td>
<td>47 (19) (20–120)*</td>
<td>80 (39) (40–260)*</td>
<td>99 (31) (60–180)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum block (%)</td>
<td></td>
<td>94 (6) (76–100)</td>
<td>93 (6) (78–100)</td>
</tr>
<tr>
<td>Lag time (s)</td>
<td></td>
<td>41 (14) (10–80)</td>
<td>41 (14) (20–60)</td>
</tr>
<tr>
<td>90% block T₁/T₀ (s)</td>
<td></td>
<td>71 (39) (30–240)</td>
<td>89 (28) (50–150)</td>
</tr>
<tr>
<td>Onset time (s)</td>
<td></td>
<td>80 (39) (40–260)*</td>
<td>99 (31) (60–180)</td>
</tr>
</tbody>
</table>

received randomly, in a double-blind fashion, rocuronium 0.6 mg kg⁻¹ (2×ED₉₅), rocuronium 0.9 mg kg⁻¹ (3×ED₉₅) or succinylcholine 1 mg kg⁻¹, injected over 15 s into a fast-flowing intravenous infusion of Ringer’s solution. No further dose of neuromuscular blocking drug was given.

The times from the end of injection of the neuromuscular blocking drug to the first twitch depression, to 90% block and to the maximum twitch depression (lag time, 90% depression T₁/T₀ and onset time, respectively) and the maximum block were measured. The clinical duration of neuromuscular block at the adductor pollicis muscle was measured using the AMG; after reaching the maximum block, train-of-four stimulation was started at the right adductor pollicis muscle every 15 s; times for the first twitch response (T₁/T₀) to return to 25, 75 and 90% and for the TOF to reach 0.7 were measured.

The results are expressed as mean (SD) and range. The physical characteristics of the three groups were compared using analysis of variance (ANOVA) and corrected according to the number of comparisons (Bonferroni), P<0.05 was regarded as significant. The pharmacodynamic variables were compared within the groups between the different monitoring sites using the paired-sample t-test, and analysis of variance (ANOVA) was used between groups, corrected for the number of comparisons (Bonferroni); P<0.05 was regarded as significant.

The correlation between lag time, 90% block, onset time and maximum effect at the two muscle sites within groups was analysed using Pearson’s test; P<0.05 was regarded as significant.

**Results**

Patient characteristics are shown in Table 1. Mean age of the patients was 52 yr (range 20–81), and 65% were female. All patient data in the three groups were comparable and did not show any significant difference. In all patients, determination of supramaximal stimulation at all three monitoring sites was successful and the laryngeal electrode was still attached to the tracheal tube at the time of extubation.

No side-effects due to transcutaneous stimulation of the recurrent laryngeal nerve with a mean current of 40 mA (range 25–55 mA), such as cardiac arrhythmias and skin irritation, were noted. Postoperative laryngoscopic examination did not show any alteration or damage (e.g. haematoma or granuloma) to the vocal cords due to stimulation or placement of the laryngeal electrode.

The mean amplitude of the EMG response to placement of the laryngeal electrode at the adductor laryngeal muscles was 0.9 (0.5) mV (0.4–2 mV) after supramaximal stimulation. Comparison of the onset of neuromuscular blockade at the two monitoring sites showed that, for both drugs, the lag time, 90% block and onset time were significantly shorter at the larynx than at the adductor pollicis, with no significant differences between EMG and AMG measurements (P<0.01, Table 2); the mean maximum effect reached at
the three sites in the three groups was >93% and did not differ statistically between groups.

The comparison of the pharmacodynamic data for rocuronium compared with succinylcholine showed that the lag times for succinylcholine 1 mg kg⁻¹ were not significantly different from those for rocuronium 0.6 and 0.9 mg kg⁻¹ at the larynx or for the three drugs at the adductor pollicis muscle, nor was there a significant difference between the rocuronium groups at the two monitoring sites (Table 2).

At the adductor pollicis muscle, 90% block and the onset time were significantly shorter in the succinylcholine group (P<0.01) than in both rocuronium groups (Table 2). The 90% block and onset time of succinylcholine at the larynx were significantly shorter than for both doses of rocuronium, and the times for rocuronium 0.6 mg kg⁻¹ were significantly longer than for rocuronium 0.9 mg kg⁻¹ (Table 2). There was no correlation of the lag time, 90% block or onset time in the three groups between the larynx and the adductor pollicis muscle.

The clinical duration using AMG at the adductor pollicis muscle is shown in Table 3; the clinical duration was shortest for succinylcholine, followed by rocuronium 0.6 and 0.9 mg kg⁻¹.

### Discussion

We have shown that, at the larynx and adductor pollicis muscle, succinylcholine 1 mg kg⁻¹ has shorter onset times and a narrower range of effect than both doses of rocuronium, even 0.9 mg kg⁻¹; lag and onset times were shorter at the larynx than at the adductor pollicis muscle. The clinical duration of neuromuscular block, as measured at the adductor pollicis muscle using AMG, was much shorter for succinylcholine, as would be expected.

Evoked electromyographic responses monitored using a disposable surface electrode attached to a tracheal tube were used to measure the onset of block at the larynx. The technique proved reliable in 90 patients and was easy to use without any major technical problems. It was connected to a standard EMG-monitoring device (Multiliner®); recording was performed using modified nerve conduction software, providing not only information about the amplitude of the compound action potential but also about the latency and duration of the signal. It could be recorded in all patients. Since patients were undergoing thyroid surgery, only the onset of neuromuscular block could be measured in this way; monitoring of the duration of the neuromuscular block at the larynx would have meant delaying the start of surgery for almost 1 h in the rocuronium 0.9 mg kg⁻¹ group and was therefore omitted. We did, however, monitor nerve integrity in all patients, because the surface laryngeal electrode was used to monitor and identify the recurrent laryngeal nerve intraoperatively. In all patients, a compound action potential could still be traced and recorded after a mean of 2.5 h of surgery. We showed in another study⁸ that the surface laryngeal electrode was able to deliver reliable evoked EMG signals for up to 6 h.

All patients were routinely checked 3 days after operation by an otolaryngologist who was not aware of the study, or by the use of the surface electrode, for any lesion or damage to the vocal cords or impairment of vocal cord function; none was found. Transcutaneous stimulation of the laryngeal recurrent nerve was possible in all patients in the same manner as that demonstrated by Donati and colleagues⁹ to produce contraction of the adductor laryngeal muscles. No harm from the stimulation, such as burns, skin irritation and cardiac arrhythmia, was noted. The comparison of the two drugs was undertaken for several reasons: rocuronium 0.6 mg kg⁻¹ is widely used for intubation in our clinical setting, and provides a peak effect sufficient to ensure good intubation conditions with a reasonable onset time, and rocuronium 0.9 mg kg⁻¹ is used in clinical practice to produce onset times equivalent to those given by succinylcholine 1 mg kg⁻¹.

Meistelman and colleagues¹⁰ investigated the onset and duration for rocuronium 0.5 mg kg⁻¹ in 14 patients. They found an onset time of 1.4 (0.1) min at the vocal cords with only 77 (5)% maximum blockade; recovery time to 90% T₁/T₀ was 22±3 min using a cuff pressure method in which the pressure change in the cuff of a tracheal tube placed between the vocal cords was evaluated.

Wright and colleagues¹¹ used the same method and compared succinylcholine 1 mg kg⁻¹ with rocuronium at, among other doses, 0.8 mg kg⁻¹; succinylcholine had a much faster laryngeal onset than rocuronium (34 (12) vs 96 (45) s) and a much narrower range of effect (18–58 vs 44–183 s), with peak effects similar to those found in the present study.

In a recent study, D’Honneur and colleagues¹² used a specially designed tracheal tube to measure onset and clinical duration for succinylcholine 1 mg kg⁻¹ and
rocuronium 0.6 mg kg\(^{-1}\) at the larynx. There was a much faster onset and shorter duration for succinylcholine than for rocuronium, onset time being 58 (10) s (45–75) vs 124 (39) s (70–175) and recovery to 90% \(T_1/T_0\) 8.3 (3.2) min (5.7–14.5) vs 34.9 (7.6) min (26.3–46.2). This is in concordance with our findings.

Whether a neuromuscular blocking drug can be used to replace succinylcholine for RSI is also related to its clinical duration. It is questionable whether it is important that complete relaxation of the larynx occurs after 47 s, as with succinylcholine 1 mg kg\(^{-1}\), or after 64 s, as with rocuronium 0.9 mg kg\(^{-1}\). However, the return of neuromuscular transmission at the larynx to control levels after 5–10 min or 30–45 min might define whether a patient survives the ‘can’t intubate–can’t ventilate’ situation. Another important difference in the onset time of rocuronium in comparison with succinylcholine is the larger interindividual variability. Reliable and sufficient relaxation after a given onset time is more predictable with succinylcholine.

Because of its much longer duration of action and greater interindividual variability, we would not recommend rocuronium 0.9 mg kg\(^{-1}\) as a substitute for succinylcholine 1 mg kg\(^{-1}\) for RSI, unless there are contraindications to the use of succinylcholine.

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