Surface *vs* intramuscular laryngeal electromyography

Thomas M. Hemmerling MD DEAA,
J. Schmidt MD,
Tobias Wolf,
Stephan R Wolf MD,*
Klaus E. Jacobi MD

Purpose: To compare surface and intramuscular laryngeal electromyography (EMG) with adductor pollicis muscle EMG after $0.1 \text{ mg}\cdot\text{kg}^{-1}$ cisatracurium.

Methods: This prospective study included ten patients undergoing surgery with risk of damage to the recurrent laryngeal nerve (RLN). The tracheas were intubated after fentanyl/propofol without the aid of muscle relaxation. A surface laryngeal electrode was attached to the tube and placed amidst the vocal cords; two straight needles were inserted endoscopically into the left lateral cricoarytenoid muscle. Single twitch stimulation of the left RLN (0.1 Hz) was performed transcutaneously; skin EMG of the left adductor pollicis muscle was performed at 0.1 Hz . After supramaximal stimulation for 10 min, $0.1 \text{ mg}\cdot\text{kg}^{-1}$ cisatracurium was injected. Lag, onset time and peak effect were measured and compared.

Results: Good correlation ($r = 0.9, 0.8, P < 0.005$) and good comparability of the two methods of laryngeal EMG (mean difference and limits of agreement: $0 \pm 28 \text{ sec}$ for lag time, $-2 \pm 84 \text{ sec}$ for onset time) was shown. The mean surface laryngeal lag and onset times were $67 \pm 22 \text{ sec}$ and $198 \pm 72 \text{ sec}$, compared with the adductor pollicis muscle ($98 \pm 30 \text{ sec}$ and $242 \pm 59 \text{ sec}$) at $P < 0.01$. Peak effects at larynx ($92 \pm 9\%$) and adductor pollicis muscle ($95 \pm 3\%$) were similar.

Conclusion: Surface laryngeal EMG is comparable to intramuscular laryngeal EMG to determine degree and onset of the neuromuscular blockade. Increasing muscle relaxation does not cause the surface electrode to lose contact with the vocal cords and therefore underestimate onset time and peak effect.

Objectif : Comparer l'électromyographie (EMG) laryngée de surface et intramusculaire avec l'EMG de l'adducteur du pouce après l'administration de $0,1 \text{ mg}\cdot\text{kg}^{-1}$ de cisatracurium.

Méthode : Il s'agit d'une étude prospective auprès de dix patients qui subissent une intervention chirurgicale comportant un risque de dommages au nerf récurrent (NR). La trachée a été intubée après l'administration de fentanyl/propofol sans l'aide de myorelaxant. Une électrode laryngée de surface a été fixée au tube et placée au niveau des cordes vocales; deux aiguilles droites ont été insérées sous endoscope dans le muscle crico-aryténoïdien latéral gauche. Une stimulation transcutanée unique du NR gauche de $0,1 \text{ Hz}$ a été réalisée; l'EMG cutanée de l'adducteur du pouce gauche a été faite à $0,1 \text{ Hz}$. On a injecté $0,1 \text{ mg}\cdot\text{kg}^{-1}$ de cisatracurium à la suite d'une stimulation supramaximale de 10 min. On a mesuré et comparé l'effet selon la période de latence, le début d'action et l'effet maximal.

Résultats : Une bonne corrélation ($r = 0,9; 0,8; P < 0,005$) et une bonne comparabilité des deux méthodes d'EMG laryngée (différence moyenne et limites : $0 \pm 28 \text{ s}$ pour la période de latence, $-2 \pm 84 \text{ s}$ pour le début d'action) ont été démontrées. Les périodes de latence et temps d'action moyens de l'EMG laryngée de surface ont été de $67 \pm 22 \text{ s}$ et de $198 \pm 72 \text{ s}$, comparativement à l'adducteur du pouce ($98 \pm 30 \text{ s}$ et de $242 \pm 59 \text{ s}$) à $P < 0,01$. L'effet maximal au larynx ($92 \pm 9 \%$) et à l'adducteur du pouce ($95 \pm 3 \%$) a été similaire.

Conclusion : L'EMG laryngée de surface est comparable à l'EMG laryngée intramusculaire pour déterminer le degré et le début d'action du blocage neuromusculaire. L'augmentation du relâchement musculaire n'agit pas sur l'électrode de surface en contact avec les cordes vocales et, en conséquence, ne provoque pas de sous-estimation du début d'action ou de l'effet maximal.

From the Departments of Anesthesiology and ENT-Surgery,* University Erlangen-Nuremberg, Germany.

Address correspondence to: Dr. T.M. Hemmerling, Postfach 1367, 66363 St. Ingbert, Germany.

E-mail: thomashemmerling@hotmail.com

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ELECTROMYOGRAPHY (EMG) has been used to measure evoked responses of laryngeal muscles, especially in surgery of the thyroid gland or neck dissection, where damage to the recurrent laryngeal nerve is a serious complication. Different electrodes have been investigated to record evoked electromyographic responses, especially straight needle electrodes directly into the vocalis muscle from the surgical site¹ or endoscopically inserted into the adducting laryngeal muscles.²⁻⁴ More recently, a less invasive, disposable surface laryngeal electrode has been described.⁵ Experience with electrodes used for intraoperative nerve monitoring has made it possible to use surface EMG of the larynx to determine the onset, offset and degree of the neuromuscular blockade (NMB) of muscle relaxants at the larynx.⁶⁻⁷

However, there are doubts whether methods of monitoring the laryngeal response using devices relying on contact between the monitoring device and the vocal cords, such as the cuff pressure method, are accurate in determining onset and peak effect of the NMB at the larynx.⁸ With progressing NMB, the diameter of the laryngeal sinus widens⁹ and the onset time and the peak effect of the NMB might be underestimated. Only when the resting cuff pressure is restored, proper measurements can take place.⁸

We have presented a new method of surface laryngeal EMG monitoring for determination of NMB.⁷ The purpose of this study was to confirm that increasing NMB and laryngeal sinus diameter might not cause loss of contact between surface electrode and vocal cords and, thus, underestimate peak effect and onset time. We therefore compared onset and peak effect of the NMB of cisatracurium using surface laryngeal with intramuscular EMG via straight needle electrodes.

Material and methods

After approval of the institutional human investigation committee and after obtaining written informed consent, 10 patients, undergoing surgery of the thyroid gland or neck dissection, were included in the study.

Pregnant women, patients with neuromuscular, hepatic, or renal disease or patients receiving medication known to interact with neuromuscular blocking drugs were excluded from the study.

In the anesthetic room, standard monitoring was established including electrocardiography, pulse oximetry and non-invasive blood pressure, measured every five minutes on the right arm. Anesthesia was induced with 4 $\mu\text{g}\cdot\text{kg}^{-1}$ fentanyl. A target-controlled infusion of propofol (target concentration: 4 $\mu\text{g}\cdot\text{ml}^{-1}$) was started, programmed to reach the target concentration within two

minutes. After induction of anesthesia, the lungs were mask-ventilated for two minutes and intubation was performed using a routine Woodbridge-tube (Mallinckrodt, UK, size 7.0: female, size 8.0: male) with the surface laryngeal electrode (Magstim company, UK) attached 2 cm above the beginning of the cuff (Figure 1). Care was taken to place the electrode amidst the vocal cords for optimal EMG-tracing. (All patients were checked for recurrent laryngeal nerve function three days postoperatively via indirect laryngoscopy by the ENT-specialist; any lesion or damage to the vocal cords was also noted).

After intubation, straight needle electrodes (Figure 1) were applied endoscopically; two needles were introduced on the left side into the lateral cricoarytenoid muscle and secured; the indifferent electrode was inserted into the forehead skin.

FIGURE 1 Surface electrode and needle electrodes; the surface electrode is already attached to the tube, the recording part glued circumferentially around the tube, 2 cm above the cuff, and later on placed between the vocal cords. The recording part covers an area of 2 x 2 cm; six leads are vertically integrated into that area, three for each side. After stimulation of the left recurrent laryngeal nerve, three leads of the left side are used for recording. The needle electrodes are both endoscopically inserted into the left lateral cricoarytenoid muscle and connected to the recording machine

Anesthesia was maintained with target-controlled infusion of propofol (target concentration: $3 \mu\text{g}\cdot\text{ml}^{-1}$) and $2 \mu\text{g}\cdot\text{kg}^{-1}$ fentanyl at the discretion of the anesthesiologist. Mechanical ventilation was adjusted to achieve $P_{\text{et}}\text{CO}_2$ of 28-35 mmHg.

After the induction of anesthesia and fixation of the tube, the recurrent laryngeal nerve was stimulated at the notch of the thyroid cartilage transcutaneously with an external nerve stimulator (Nicolet Viking® II; Nicolet Biomedicals, Germany). This method produces a maximum response of the adducting laryngeal muscles.¹⁰ Single twitch-stimulation (0.1 Hz, pulse width: 0.2 msec) was performed on the left recurrent nerve to determine the supramaximal stimulation and recorded using the same device. The current was increased from 0 to that which produced the maximal EMG-response (<70 mA) and then was increased further by 10 mA to ensure supramaximal stimulation. The amplitudes of the compound action potential were measured and recorded. The NMB of the left adductor pollicis muscle was measured via EMG using skin surface electrodes (Ag-AgCl-electrodes) placed over the ulnar nerve for stimulation and two electrodes placed over the thenar area for recording; the Nicolet Viking® was used for simultaneous recording. Supramaximal stimulation was performed with a current of 0-70 mA, single twitch stimulation was performed simultaneously with stimulation of the recurrent laryngeal nerve.

After no change in the neuromuscular response could be detected at all sites for 10 min, the patients received $0.1 \text{ mg}\cdot\text{kg}^{-1}$ cisatracurium ($2 \times \text{ED}_{95}$) *iv*, injected within 15 sec into a fast-flowing infusion of Ringer solution. No further muscle relaxant was applied.

The time from the end of injection of the muscle relaxant to the first twitch depression, the maximum twitch depression (lag time, onset time) and the peak effect (%-reduction of the maximal neuromuscular response) of the NMB were measured. The pharmacodynamic data from the different electrodes were determined by two independent examiners, blinded to each others' results. They were assigned randomly to measure the onset times derived by either surface or intramuscular EMG.

The results are expressed as mean $\pm$ standard deviation and range. Statistical analysis was performed using Student t test, corrected for the number of comparisons (Bonferroni): $P < 0.05$ was regarded as showing significant difference. Correlation analysis between surface and needle laryngeal EMG recordings was performed by Pearson's test; Bland Altman plots were used to evaluate the mean value of the difference between surface and intramuscular laryngeal EMG and the limits of agreement.

TABLE Onset time and peak effect of neuromuscular block after $0.1 \text{ mg}\cdot\text{kg}^{-1}$ cis-atracurium on the larynx and the adductor pollicis in 10 anesthetized patients

	Larynx (Surface electrode)	Larynx (Needle electrodes)
Peak effect (%)	92 ± 9 (71-100)	93 ± 6 (81-100)
Lag time (sec)	67 ± 22 (30-100)	67 ± 28 (30-130)
Onset time (sec)	198 ± 72 (110-340)	200 ± 76 (110-340)

Values are mean $\pm$ SD; values in parentheses are range

Results

The mean age of six men and four women was 52 ± 16 yr, mean weight 73 ± 12 kg. Patients were classified as ASA I (2), ASA II (4) and ASA III (4). Mean time of surgery was 2.5 ± 0.8 hr (range: 1 to 4.5 hr).

Determination of the supramaximal stimulation was successful in all patients.

The mean amplitude of the EMG-response of the surface laryngeal electrode at the adducting laryngeal muscles was 1.2 ± 0.2 mV after supramaximal stimulation and 4.3 ± 2.3 mV when needle electrodes were used.

The peak effect, lag and onset times at the larynx were not different between surface and intramuscular EMG (Table).

The lag and onset times were longer at the adductor pollicis muscle at 98 ± 30 sec, 242 ± 59 sec ($P < 0.01$) than at the larynx; the peak effect at the adductor pollicis muscle, at $95 \pm 3\%$, not different from that at the larynx.

There was a correlation between lag time and onset time of the surface electrode and the needle electrodes ($r = 0.9, 0.8$; $P < 0.005$); the peak effects correlated at $r = 0.8$, $P < 0.005$. The mean difference and the limits of agreement for the lag time between surface and needle electrodes were 0 ± 28 sec, for the onset time -2 ± 84 sec (Figures 2a,b).

In all patients, the surface laryngeal electrode was still attached to the tube at the time of extubation, the needle electrodes were checked endoscopically prior to extubation, and all were in correct position. The needle electrodes were removed before extubation; in all patients, no side effects such as hematoma or swelling due to the needles occurred at postoperative control three days after surgery.

No side effects such as arrhythmias or skin irritation due to transcutaneous stimulation of the recurrent nerve were noted. The postoperative laryngoscopic

FIGURE 2A

FIGURE 2B

examination did not show any alteration or damage of the vocal cords due to the stimulation of the surface laryngeal electrode or the laryngeal electrode itself.

Discussion

Our study shows that the mean onset times, derived from surface and intramuscular laryngeal EMG, were almost identical (198 sec for surface electrode *vs* 200 sec for needle electrodes), correlated well at $r = 0.8$ and showed good comparability by Bland Altman analysis (mean difference: -2 sec) with similar mean peak effects of 92 and 93%, respectively. The onset of the NMB after 0.1 mg·kg⁻¹ cisatracurium occurred

about 45 sec earlier at the larynx than at the adductor pollicis. The clinical duration of cisatracurium was not measured because it would have meant to postpone surgery for at least one hour due to transcutaneous stimulation at the neck, thus within the surgical field. Economic reasons and the fact that it was not the main purpose of this study led us to refrain from measuring the clinical duration of the NMB.

The onset of NMB at the larynx after cisatracurium has not been reported currently. Rimaniol *et al.*¹¹ studied tracheal intubation conditions after either 0.15 or 0.2 mg·kg⁻¹ cisatracurium in 60 patients. Tracheal intubation was commenced at 120 sec and the mean time to achieve intubation noted. After 0.15 mg·kg⁻¹, at a mean of 149 sec, 6 of 30 patients showed poor and 24 of 30 patients showed good or excellent conditions. After 0.2 mg·kg⁻¹ cisatracurium and 137 sec, only one of 30 patients had poor intubating conditions.

The straight needle electrodes are inserted endoscopically into the lateral cricoarytenoid muscle and EMG recording reflects responses from this muscle. Whereas surface laryngeal EMG reflects mostly the response of the thyroarytenoid muscles but other more distant laryngeal adductor muscles such as the lateral cricoarytenoid or cricothyroid muscles also contribute to the compound action potential. The resulting compound action potential should be considered as the response of several adducting laryngeal muscles.

The tube with the surface electrode attached approximately 2 cm above the cuff moves during respiration. The length of the recording part of the surface electrode is about 1.5 cm. Furthermore, in contrast to surface skin electromyography at the adductor pollicis muscle, the recording electrode is not glued or attached firmly to the vocal cords, but relies on close contact between the recording part of the electrode and the vocal cords. This might cause recording problems with weakening EMG signals during progressing block intensity. It might be argued that the weakening neuromuscular response might be better recorded using intramuscular needle electrodes than a surface electrode. However, the mean onset time measured using intramuscular needle and surface electrodes, showed only minimal mean difference of -2 sec. The limits of agreement for the onset time were 84 sec, which is acceptable for different recording electrodes.

Sivarajan *et al.*⁹ showed with radiograph imaging of the neck in ten patients that the laryngeal sinus, the space bounded superiorly by the vestibular folds and inferiorly by the vocal folds, increased from 1.6 mm to a mean of 3.3 mm after administration of 1.5 mg·kg⁻¹ succinylcholine and 3-5 mg·kg⁻¹ thiopental. Surface electromyography might then underestimate the onset

time and the peak effect because, with increasing NMB, the contact between vocal cords and electrode might decrease or be lost.

The theory that monitoring methods relying on superficial contact between electrodes or monitoring devices (such as cuff pressure method) and vocal cords might be influenced by diminishing contact areas and widening laryngeal sinus with increasing NMB was investigated by Girling *et al.*⁸ using video imaging to estimate NMB. They compared this technique with the cuff pressure technique introduced by Donati *et al.*¹⁰ and used almost entirely throughout the last decade for objective monitoring of the NMB at the larynx. However, there were a few critical points in that study. Both methods were compared at a preset closed-loop operated NMB of 50% or 75% block at the adductor pollicis muscle and lag time, onset time and peak effect at the larynx were not measured. The degree of the block was measured using the cuff pressure method and then, because the cuff pressure decreased after administration of the muscle relaxant, after restoration of the control cuff pressure. Only when resting cuff pressure was restored after relaxation, was the degree of block measured with the two methods comparable at the larynx. For 50% block, the mean difference between cuff pressure and video imaging methods was $2\% \pm 22\%$ limits of agreement. It is not stated whether the degree of laryngeal block assessed by cuff pressure and video imaging was determined by the same observer or whether the observer was blinded to the cuff pressure method before judging laryngeal block by video imaging.

Video imaging is based on subjective viewer interpretation, and the reproducibility of the cord movement at different stimulation levels, adequacy of the 25 frame/sec video tracing and the stability of the cord movement over time need to be confirmed.

In the current study intramuscular needle electrodes were regarded as the gold standard of EMG recording electrodes if they remain on site during measurements which was checked after extubation. There are no studies that have compared surface electrodes and needle electrodes simultaneously for measuring NMB. O'Donnell *et al.*¹² compared EMG wave forms in 40 elderly male patients undergoing multiple urodynamic evaluations from different forms of surface electrodes with concentric needle electrodes. They concluded that, with secure attachment of the surface electrode to the skin, proper anatomic placement of the electrode, appropriate preparation of the skin surface at the site of application of the electrode, surface electrodes can record a signal amplitude and frequency approaching the quality of concentric nee-

dle electrodes. There are no data on the influence of different types of surface electrodes on the pharmacodynamic measurements of NMB.

The conformity between our results obtained using the needle electrodes and the surface electrode suspects that widening of the laryngeal sinus does not impair surface EMG responses. The lag time, onset time and peak effect are comparable between the two methods. Surface EMG is a simple easy method to measure laryngeal onset and peak effect of muscle relaxants.

We conclude that disposable surface electrode attached to the endotracheal tube is a means to record the evoked EMG-responses. There is no difference between the onset times and peak effect measured using this electrode to times and peak effects after cisatracurium measured using intramuscular needle electrodes inserted into adducting laryngeal muscles. Surface EMG is non-invasive and easy to use, but delivers the same sensitivity for recording the laryngeal NMB.

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