ORIGINAL RESEARCH

An experimental study on intraoperative recovery of recurrent laryngeal nerve function

Erling J. Setså[1] | Øyvind S. Svendsen[2] | Paul J. Husby[2] | John-Helge Heimdal[3,4] | Lodve Stangeland[4] | Geir O. Dahle[2] | Katrin Brauckhoff MD, PhD[1,4] (iD)

[1]Department of Breast and Endocrine Surgery, Haukeland University Hospital, Bergen, Norway

[2]Department of Anesthesia and Intensive Care, Haukeland University Hospital, Bergen, Norway

[3]Department of Surgery, Haukeland University Hospital, Bergen, Norway

[4]Department of Clinical Sciences, University of Bergen, Bergen, Norway

Correspondence
Katrin Brauckhoff, MD, PhD. Department of Breast and Endocrine Surgery, Haukeland University Hospital, Jonas Lies vei 65, N-5021 Bergen, Norway.
Email: katrin.brauckhoff@helse-bergen.no

Funding information
Grieg Foundation; Helse Vest, Grant/Award Number: 400031

Abstract

Objective: If bilateral thyroid surgery is planned and staged thyroidectomy considered in case of loss of neuromonitoring signal (LOS), a waiting time of 20 minutes is suggested for evaluation of early nerve recovery. This recommendation is based on clinical observations and has not been thoroughly validated experimentally.

Methods: Sixteen pigs were randomly studied, and electromyogram (EMG) was continuously recorded during traction injury until an amplitude decrease of 70% from baseline (BL) (16 nerves) or LOS (16 nerves), and further during 40-minute recovery time. At the end of the experiments, vocal cord twitch was evaluated by video-laryngoscopy.

Results: In the 70% group, 8 of 16 nerves recovered to or above an amplitude of 50% of baseline after 20 minutes and finally one more after 40 minutes. In the LOS group, only one nerve showed recovery after 20 minutes and one more after 40 minutes. Video-laryngoscopy revealed good or strong vocal cord twitches, in 10 of 14 nerves in the 70% group and in only 2 of 14 nerves in the LOS group.

Conclusions: The overall intraoperative recovery was low after LOS. Even after 70% amplitude depression, only half of the nerves showed recovery to amplitudes ≥50% of BL. Nerve recovery is dynamic, and a waiting time of 20 minutes seems appropriate for the identification of early nerve recovery before decisions are taken to continue or terminate surgery. The final EMG amplitude was not always well correlated with estimated vocal cord twitch, evaluated by video-laryngoscopy. This observation needs further investigation.

KEYWORDS
intraoperative neuromonitoring, recurrent laryngeal nerve recovery, vocal cord twitch

1 | INTRODUCTION

Implementation of continuous intraoperative neuromonitoring (C-IONM) gives the opportunity to real-time surveillance of the recurrent laryngeal nerve (RLN) during thyroid mobilization and nerve dissection. C-IONM compared to intermittent IONM (I-IONM) recognizes impending nerve injury and enables the assessment of intraoperative recovery of nerve function after loss of the

electromyographic (EMG) signal.[1] Thereby C-IONM offers the possibility to change surgical strategy in case of adverse EMG changes to avoid serious nerve injury with concomitant vocal cord dysfunction. Still, however, with the occurrence of loss of EMG signal (loss of neuromonitoring signal [LOS]) the presence of vocal cord palsy (VCP) is most likely.[2]

The practice of staged thyroidectomy was established to reduce the devasting postoperative complication of bilateral VCP following intraoperative injury of both RLN. Two-staged thyroidectomy has in this context been recommended after LOS on the first surgical side in bilateral planned surgery. Continuation of surgery on the second side after initial LOS has been reported with a 16% rate of bilateral VCP vs zero in staged procedures.[3] However, the positive predictive value (PPV) for VCP after LOS is well below 100%, and postoperative laryngoscopy may show normal vocal cord function, even when surgery was discontinued because of LOS. Consequently, nerve function may recover after intraoperative LOS with sufficient postoperative vocal cord movement, and staged surgery seems to be unnecessary in these cases. Schneider et al found that all patients with LOS who had recovery to a final amplitude ≥50% of their baseline amplitude had normal vocal cord function postoperatively.[4] The guidelines from the International Neural Monitoring Study Group (INMSG) recommend that EMG recovery should be considered when the final amplitude is more than 250 μV and above 50% of the baseline. Furthermore, the INMSG suggests a 20-minute waiting time after LOS to evaluate possible early nerve recovery.[5] This information is essentially based on clinical observational studies where vocal cord function was evaluated by direct laryngoscopy within 48 hours after surgery.[1,6]

Most VCPs are transient and time to normal vocal cord function is variable depending on the severity of nerve trauma and cannot be exactly predicted. Different injury mechanisms of the RLN may induce different morphological alterations that may affect nerve recovery.[7] Traction to the RLN is the most frequent reason for intraoperative LOS,[2] and nerve recovery after traction injury is faster when compared to other injury mechanisms.[7] Several experimental studies have investigated and described EMG signal recovery after nerve injury using C-IONM, however, to our knowledge none of them examined corresponding vocal cord movement.[8-12] In the present study using a porcine model, we compared EMG signal recovery from LOS or 70% amplitude depression after traction injury of the RLN. EMG data were correlated to "range of motion (ROM) of vocal cord" graded by immediate direct video-laryngoscopy at the end of operation.

2 | MATERIALS AND METHODS

2.1 | Animals, animal handling, and anesthesia procedure

Sixteen anesthetized, locally bred immature domestic pigs (Norwegian Landrace, Norhybrid) were studied, and 32 RLNs were included. The study was approved by the Norwegian Animal Research Authority, Oslo, Norway (FOTS, ID 13904-2018) and conducted under surveillance of the institutional Animal Use and Care Committee according to the National Institute of Health Guidelines for Care and Use of Laboratory Animals. All animals were acclimatized for 1 week in the laboratory housing area before the experiments. Prior to the experiments, all animals were fasted overnight, but always with free access to water. Normothermic body core temperature was preserved by use of a heating mattress and covering blankets. Body core temperature was obtained via a urinary catheter placed in the urinary bladder. Acid-base parameters and serum electrolytes were measured throughout the experiments.

At the end of each experiment, the pigs were euthanized by an intravenous injection of 20 mL of saturated potassium chloride solution.

Preanesthetic medication with ketamine 500 mg, diazepam 10 mg, and atropine 1 mg was given intramuscularly 30 minutes prior to induction of general anesthesia. General anesthesia was introduced with isoflurane in oxygen administered via a facemask and supplemented with thiopentone (5 mg/kg body weight) intravenously 2 minutes before intubation of the trachea (NIM-FLEX EMG-endotracheal tube; 6.5 mm ID × 8.9 mm OD; 27FR; Medtronic Xomed, Jacksonville, Florida). General anesthesia was maintained with administration of isoflurane (1.5-2.0 vol%) in oxygen/air via volume-controlled normoventilation (end-tidal carbon dioxide level of approximately 5.0 kPa) (Dräger anesthesia workstation; Dräger, Lübeck, Germany) and supplemented by an infusion of midazolam (0.5 mg/kg/h) and fentanyl (7.5 μg/kg/h) as previously described.[13] Neuromuscular blocking agents were completely avoided at all time intervals during the experiments.

2.2 | Hemodynamic monitoring, acid-base parameters

Heart rate was followed by electrocardiography (ECG) obtained by surface ECG electrodes. Systemic mean arterial pressure (MAP) was followed by a fluid-filled catheter introduced into the right femoral artery, connected to a pressure transducer (Transpac 4, ICU Medical, San Clemente, California) linked to IntelliVue monitor (Philips, Böblingen, Germany). Acid-base parameters (pH, pCO_2 and base excess) were recorded at start and during the experiments.

2.3 | Surgical preparation, EMG, and video-laryngoscopy

After preparation and surgical disinfection, neck and larynx were exposed by a low horizontal incision and vertical split of the upper skin and platysma. The vagus nerve was identified visually and by use of a conventional handheld monopolar stimulation probe (4 Hz, 100 μS, 1 mA; NIM 3.0 Nerve Monitoring System; Medtronic, Minneapolis, Minnesota). An automatic periodic stimulation electrode (APS Electrode Stimulator Probe, 2.0 mm; Medtronic) was placed on the vagus nerve. Before the start of data collection, the tube was

brought to position for optimal amplitude registration at baseline. The ipsilateral RLN was identified visually and by the handheld probe. A vessel loop was gently wrapped around the RLN for application of nerve traction. Preparation was kept minimal to preserve all connective tissue surrounding the nerves.

Stimulation of the vagus nerve via the APS electrode was performed by use of C-IONM (NIM 3.0; Nerve Monitoring System; Medtronic). After baseline EMG recordings traction stress was initiated by attaching a weight system to a vessel loop via a pulley yielding a constant sideways lateral traction force to the RLN of 1.0 N until an EMG amplitude decrease from baseline of either 70% or LOS (amplitude <100 μV), respectively. Selection of amplitude reduction from baseline and order of nerves studied (left or right RLN) followed randomly by block randomization.

After the desired level of stress was reached, reflected by 70% amplitude decrease from baseline or LOS, the traction stress was released, and the nerve was allowed 40-minute recovery. EMG amplitude and latency were recorded the next 40 minutes. Thereafter, the nerve on the contralateral side was studied, using the same protocol.

After the studies were finalized on both the left and right sides, the animals were extubated and thereafter supplied continuously with high-flow oxygen during immediate video-laryngoscopy (Pentax Medical Vivideo Video-Naso-Pharyngo-Laryngoscope VNL9-CP; PENTAX Europe GmbH, Hamburg, Germany) to assess the subjective ROM following alternate stimulation by C-IONM. These video recordings were thereafter judged blinded by an experienced laryngologist for assessment and grading of ROM.

2.4 | Statistics

Statistical analysis was performed with Graph-Pad InStat, version 3.01 (Graph-Pad Software, San Diego, California) and IBM SPSS Statistics, version 24 (SPSS Inc., Chicago, Illinois). One-way analysis of variance with post-testing (Tukey-Kramer) if $P < .05$, was used for analysis of hemodynamic parameters whereas acid-base parameters, and serum-electrolytes were compared at start and end with paired t test (Graph-Pad InStat).

Recovery of the EMG amplitudes 20 and 40 minutes after release of nerve traction were analyzed by independent samples t tests and paired t tests (IBM SPSS Statistics). Significance level was defined as $P < .05$.

3 | RESULTS

Sixteen animals with an age of 84 (14) days (mean [SD]) and a body weight of 43.7 (3.8) kg were studied. Hemodynamic parameters, body core temperature, acid-base parameters, and serum electrolytes remained stable during the experiments (Table 1).

Figure 1 displays the EMG amplitude at baseline and following sustained RLN traction until either 70% amplitude decrease from baseline or LOS, and following 20- and 40-minute recovery, respectively. Amplitude at baseline was in the 70% group 1382 (583) μV and in the LOS group 1503 (548) μV (mean [SD]). Corresponding values at end of traction were 413 (179) and 86 (20) μV and following 20- and 40-minute recovery (70% group vs LOS group) 781 (458) and 259 (197) μV ($P < .001$) and 821 (535) and 332 (218) μV ($P < .01$), respectively (Figure 1A).

As demonstrated by Figure 1B, latency increased following sustained RLN traction to levels above 110% of baseline in both groups and remained above 110% in the LOS group throughout 40-minute recovery in contrast to the 70% group.

Recovery of amplitude and latency 20 and 40 minutes after release of RLN traction are displayed for each single nerve in Table 2 (70% group) and in Table 3 (LOS group). In the 70% group, 8 of 16 nerves recovered to or above an amplitude of 50% of baseline after 20-minute recovery. One additional nerve reached an amplitude above 50% of BL after 40-minute recovery (Table 2). In the LOS group, only 1 of the 16 nerves recovered to an amplitude level like or above 50% of BL after 20 minutes and additionally one more nerve following 40-minute recovery.

Figure 2 displays the dynamics in EMG amplitude recovery for each single experiment in the 70% group (Figure 2A) and LOS group (Figure 2B).

Direct video-laryngoscopy was successfully performed at the end of 14 experiments and revealed a barely visible twitch of the vocal

TABLE 1 Hemodynamic parameters and body core temperature are presented at start, at change of side and at the end of the experiments

Parameter	At start	At side-change	At end
Hemodynamics			
MAP (mmHg)	63.6 (9.2)	63.6 (8.7)	62,5 (9.0)
Heart rate (beats/min)	90.8 (12.1)	91.0 (13.4)	92.9 (16.8)
Core temperature (°C)	38.5 (0.7)	38.5 (0.7)	38.7 (0.8)
Laboratory parameters			
pH	7.54 (0.04)		7.54 (0.03)
pCO$_2$ (kPa)	4.96 (0.40)		4.88 (0.30)
Base excess (mmol/L)	7.5 (1.8)		7.7 (1.8)
Serum natrium (mmol/L)	139.9 (2.1)		139.6 (2.2)
Serum kalium (mmol/L)	3.6 (0.4)		3.6 (0.4)

Note: Laboratory parameters are displayed at start and at the end of the experiments. Values are given as mean with SD in parentheses.
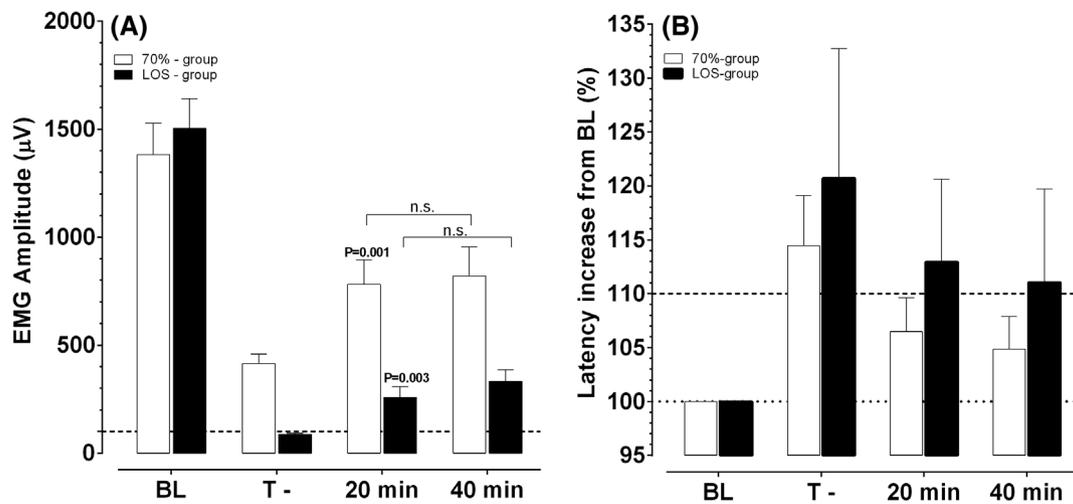
FIGURE 1 A, The electromyography (EMG) amplitude at baseline (BL), at end of sustained recurrent laryngeal nerve (RLN) traction (T−) and following 20- and 40-minute recovery. RLN traction was continued to either 70% amplitude decrease below BL (70% group) (White columns) or loss of signal (LOS group) (Black columns). Amplitudes increased significantly from T− within 20 minutes in both groups. Amplitude changes from 20 to 40 minutes were not significant in none of the groups. B, The latency increase in percent of BL values in the 70% group (White columns) and the LOS group (Black columns)

TABLE 2 Amplitude (A) and latency (L) during sustained recurrent laryngeal nerve traction to an amplitude decrease of 70% below baseline (BL) presented at BL and following 20- and 40-minute recovery, respectively

Nerve	C-IONM (70%-group) (BL)		Recovery 20 min (70%-group)				Recovery 40 min (70% group)				ROM early	ROM late	Diff.early to late (s)
	A (µV)	L (ms)	A20 (µV)	A20 (%)	L20 (ms)	L20 (%)	A40 (µV)	A40 (%)	L40 (ms)	L 40 (%)			
R.S.													
1	1125	4.50	875	77.8	4.63	102.8	793	70.5	4.63	102.8		++	4242
2	2552	4.00	759	29.7	4.25	106.3	516	20.2	4.38	109.4	++		
3	1165	5.25	504	43.3	5.63	107.2	488	41.9	5.63	107.2	n.a.		
4	2379	5.13	1473	61.9	5.38	104.9	1945	81.8	5.25	102.3	+++		
5	1570	5.88	2009	128.0	6.38	108.5	2212	140.9	6.25	106.3	++		
6	1883	5.13	674	35.8	5.38	104.9	691	36.7	5.25	102.3		++	5629
7	1750	5.25	767	43.8	5.50	104.8	898	51.3	5.50	104.8	+		
8	1085	4.75	665	61.3	5.25	110.5	643	59.3	5.00	105.3		+	4739
L.S.													
1	1942	7.25	1265	65.1	7.75	106.9	1079	55.6	7.38	101.8	n.a.		
2	1336	8.25	850	63.6	8.63	104.6	793	52.6	8.63	104.6	++		
3	958	7.75	337	35.2	8.25	106.5	382	39.9	8.13	104.9		++	9790
4	996	8.00	396	39.8	8.38	104.8	453	45.5	8.38	104.8	+		
5	624	8.88	482	77.2	9.13	102.8	521	83.5	8.88	100.0	+		
6	1170	9.00	504	43.1	10.13	112.6	467	39.9	9.88	109.8		+++	12 006
7	1046	8.13	683	65.3	8.38	103.1	753	72.0	8.38	103.1		++	4860
8	527	8.13	245	46.5	8.38	103.1	261	49.5	8.25	101.5	++		

Note: % Values refer to BL levels. Corresponding recovery of vocal cord function presented as ROM of vocal cord as early (last operated side) and late (first operated side). Evaluation scored as 0, no vocal cord movement; +, barely visible movement; ++, good movement toward the center line; +++, strong movement that affects the contralateral side. The additional recovery time in seconds (s) for the first operated side before evaluating ROM late is presented in the difference early to late column.

Abbreviations: C-IONM, continuous intraoperative neuromonitoring; L.S., left side; n.a., not available for technical reasons; ROM, range of motion; R.S.: right side.

TABLE 3 Amplitude (A) and latency (L) at Baseline (BL) and during sustained recurrent laryngeal nerve traction to loss of signal (LOS), that is, an amplitude below 100 µV and following 20- and 40-minute recovery, respectively

Nerve	C-IONM (LOS group) (BL)		Recovery 20 min (LOS group)				Recovery 40 min (LOS group)				ROM early	ROM late	Diff.early to late (s)
	A (µV)	L (ms)	A20 (µV)	A20 (%)	L20 (ms)	L20 (%)	A40 (µV)	A40 (%)	L40 (ms)	L40 (%)			
R.S.													
1	1269	4.00	192	15.1	4.50	112.5	184	14.5	4.25	106.3		n.a.	
2	1974	5.50	216	10.9	6.25	113.6	233	11.8	6.00	109.1		+	6388
3	1284	4.75	633	49.2	5.25	110.5	759	59.1	5.13	108.0	++		
4	2113	5.25	199	9.4	5.88	112.0	280	13.2	5.75	109.5		+	4084
5	1140	5.13	675	59.2	5.25	102.3	740	64.9	5.13	100.0		++	5429
6	1980	5.00	285	14.4	5.88	117.6	156	7.9	5.88	117.6	+		
7	1263	5.00	158	12.5	5.13	102.6	575	45.5	5.38	107.6	+		
8	2649	4.88	19	0.0	–	–	19	0.0	–	–		+	4662
L.S.													
1	621	9.00	293	47.2	9.88	109.7	274	44.1	9.75	108.3	+		
2	1476	7.50	296	20.1	8.38	111.7	383	25.9	8.13	108.3		+	3775
3	716	8.63	357	49.9	9.88	114.5	322	45.0	9.75	113.0		n.a.	
4	1860	8.13	142	7.6	9.00	110.7	259	13.9	8.63	106.2		++	3928
5	1156	9.63	164	14.2	11.25	116.8	470	40.7	11.38	118.2		+	5259
6	1377	8.25	42	3.0	11.13	134.9	291	21.1	11.25	136.4	+		
7	1145	8.50	474	41.4	9.50	111.8	368	35.9	9.00	105.9		+	4939
8	2032	8.00	5	0.0	–	–	5	0.0	–	–	0		

Note: % Values refer to BL levels. Corresponding recovery of vocal cord function presented as ROM of vocal cord as early (last operated side) and late (first operated side). Evaluation scored as 0, no vocal cord movement; +, barely visible movement; ++, good movement toward the center line; +++, strong movement that affects the contralateral side. The additional recovery time in seconds (s) for the first operated side before evaluating ROM late is presented in the difference early to late column.

Abbreviations: C-IONM, continuous intraoperative neuromonitoring; L.S., left side; n.a., not available for technical reasons; ROM, range of motion; R.S.: right side.
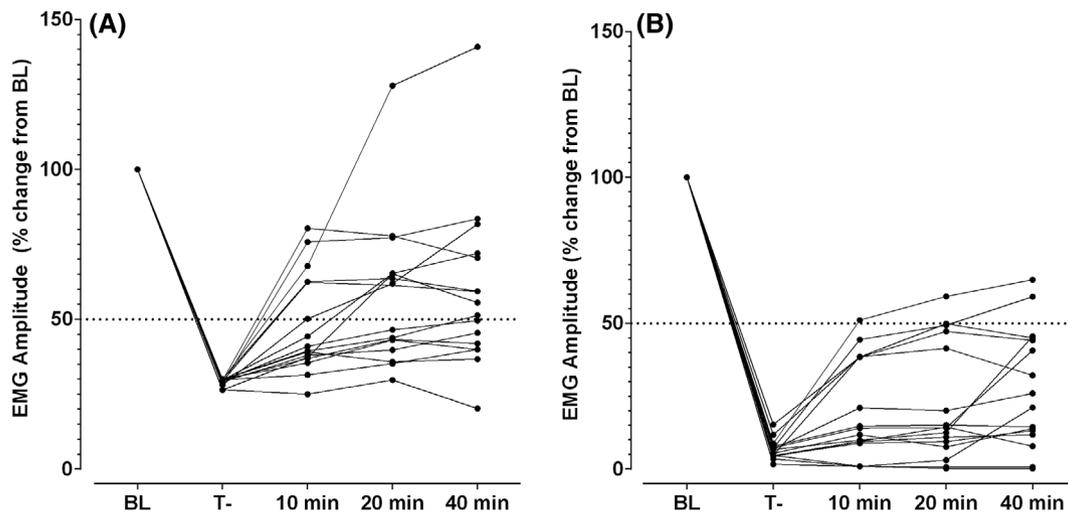

FIGURE 2 The electromyography (EMG) amplitude at baseline (BL), at end of sustained recurrent laryngeal nerve (RLN) traction (T−) and following 10-, 20-, and 40-minute recovery. RLN traction was continued to either 70% amplitude decrease below BL (70% group) (Figure 2A) or loss of signal (LOS group) (Figure 2B) and following 10-, 20-, and 40-minute recovery for each individual experiment

cord in four nerves (70% group). The mean recovery amplitude in these nerves was 59.9 (16.7) [45.5/83.5]% (mean (SD) [min/max]) of BL. In the remaining 10 nerves, a good or strong vocal cord twitch was observed with amplitudes ranging from 20% to 100% of BL and with a mean (SD) of 56.3 (24.3)%.

In the LOS group, 11 of 14 nerves showed a barely visible or no visible vocal cord twitch at video-laryngoscopic examination with amplitudes in the order of 24.1 (15.6) [0/45.5] % of BL, whereas in 3 of the 14 nerves a good vocal cord twitch could be observed with amplitudes of 46.0 (27.9) [13.9/64.9]% of BL.

Our experimental setup as described in Section 2 allowed the nerve of the first side studied to recover in average 95 minutes longer than the second nerve that recovered for only 40 minutes prior to video-laryngoscopic examination.

4 | DISCUSSION

The actual experimental work was carried out in a porcine model suitable for studies of IONM. Anatomic and physiological conditions are comparable to humans as convincingly demonstrated in numerous experimental studies performed in the porcine model.[8,9,14] Experimental setups guarantee, in contrast to clinical practice, robust conditions for body temperature, serum electrolytes, acid-base metabolism, and all-important unaltered endotracheal tube position during surgery. Intraoperative tube dislocation and its obvious effect on EMG amplitude as demonstrated by Barber et al[15], is well known from clinical routine.[16] Impaired contact between tube electrodes and the vocal cords may mimic LOS (false-positive events) during surgical preparation, but may also imitate "false recovery" if EMG amplitudes increase only by improved contact and not due to changed nerve function.

According to the latest guidelines of the INMSG, IONM adds a new functional dynamic to endocrine neck surgery.[17] Nerve integrity is guaranteed, if normal EMG-amplitude is measured by IONM. EMG amplitude seems compellingly to reflect vocal cord contractility, at least during RLN traction stress, as recently demonstrated in animal experiments comparing EMG with vocal cord accelerometry.[18] However, in clinical practice the reported accuracy of IONM for predicting VCP early after surgery is highly variable with PPVs ranging from 12% to 88%.[5]

The implementation of staged thyroidectomy in case of LOS on the first side of a planned bilateral thyroid surgery is only arguable with high PPVs avoiding unnecessary staging and in this context, correct interpretation of intraoperative signal recovery plays a fundamental role. After intraoperative LOS, EMG-amplitude may recover, however, the minimum final amplitude required to guarantee sufficient postoperative vocal cord movement is still poorly investigated.

Schneider et al reported in their clinical study, that 7 of 41 nerves with LOS (17%) showed complete recovery, 10 nerves (24%) incomplete recovery (ie, final amplitude <50% of baseline and ≥100 μV).[1] Sitges-Serras et al found in their single-center study that 15 of 40 nerves (38%) recovered after LOS to an amplitude above 100 μV.[19] In our experimental study, we observed incomplete recovery after LOS in 13 of 16 nerves (81%) after the suggested 20-minute waiting time. The higher rate of

incomplete recovery in our experimental setup, than described in clinical observational studies, may be explained by the standardized injury mechanism using only traction. Traction to the RLN is known as one of the mildest forms of neuropraxic injury with early recovery of nerve function[2,7] Recovery rates may be lower following injury by other mechanisms or after repeated LOS.

A final 13% complete recovery rate after LOS in our experiments is in the similar range as recently reported from clinical studies.[1] Schneider et al reported that all patients with intraoperative LOS and an amplitude recovery of ≥50% from their original baseline had normal postoperative vocal cord function.[4] This is also supported by our results, where the two nerves with a >50% amplitude recovery after LOS showed a good vocal cord twitch by immediate postoperative laryngoscopy.

In two of our nerves with persistent LOS, the vocal cord twitch was absent in one and in the other the vocal cord twitch was adelomorphic after 77-minute additional recovery time. Similar observations are presented from clinical praxis where about 80% of patients with persistent LOS had VCP on postoperative laryngoscopy.[2]

After incomplete EMG recovery (amplitude <50% of baseline and >100 μV) vocal cord function is difficult to predict. Schneider et al described a persistent high risk of postoperative vocal cord dysfunction of 95% after segmental LOS and of 48% after global LOS despite incomplete EMG recovery.[4] In our study, final incomplete recovery after LOS was in 92% of the nerves associated with a barely visible vocal cord twitch. Our data support the recommendation of staged thyroidectomy not only if LOS persists, but also if recovery is incomplete to avoid bilateral VCP with high risk of postoperative airway problems. In contrast, Sitges-Serra et al[19] argue for a more offensive surgical strategy as 32% of their patients with persistent LOS and about half of the patients after signal recovery had normal vocal cord function. Intraoperative drop of the EMG signal seems not always to be tantamount to nerve injury and may explain the broad variation in PPVs ranging from 12% to 88%.[5] Stringent application of an aggressive troubleshooting algorithm in case of LOS and a baseline amplitude not lower than 500 μV are requirements for high PPVs.[20,21]

According to Phelan et al amplitude reduction of 70% indicates a severe nerve trauma. In their clinical study, they found an amplitude recovery rate of 73% after a 70% amplitude drop. About 23% of their patients with an amplitude drop of 70% experienced postoperative VCP.[22] In our 70% group, 56% of the nerves showed recovery. In 29% of the nerves, video-laryngoscopy revealed a barely visible vocal cord twitch. The final vocal cord twitch was not always well correlated to the final EMG amplitude. This may be related to the difficulty subjectively quantifying the strength of the vocal cord twitch by video-laryngoscopy and needs further investigation.

5 | CONCLUSIONS

The final amplitude at the end of surgery, both relative and absolute values, seems in the majority of cases to yield crucial information

about nerve and vocal cord function. An amplitude below 100 μV is associated with an absent vocal cord twitch. Final amplitudes below 50% from BL are attended by varying strength of the vocal cord twitch. An amplitude drop of 70% below BL bears a nonnegligible risk of VCP. Objective measurements of vocal cord function at amplitude values between 100 μV and 50% below BL needs further attention.

The findings from the actual study underline the recent guidelines published by the INMSG. Nerve recovery following neuropraxia is dynamic and may increase over time as indicated both following LOS as well as an amplitude depression of 70% below BL. The suggested 20-minute waiting time after LOS, proposed by the INMSG[5], for evaluation of early nerve recovery seems appropriate according to progression of the surgical procedure, however, being aware recovery may follow within 20 minutes as well as beyond.

Recovery of nerve function during surgery is possible; however, final amplitude values should be carefully interpreted in decision making to complete or suspend a total thyroidectomy.

CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

ORCID
Katrin Brauckhoff https://orcid.org/0000-0002-2442-3281

REFERENCES
1. Schneider R, Sekulla C, Machens A, Lorenz K, Thanh PN, Dralle H. Dynamics of loss and recovery of the nerve monitoring signal during thyroidectomy predict early postoperative vocal fold function. *Head Neck*. 2016;38(suppl 1):E1144-E1151.
2. Schneider R, Randolph G, Dionigi G, et al. Prospective study of vocal fold function after loss of the neuromonitoring signal in thyroid surgery: the International Neural Monitoring Study Group's POLT study. *Laryngoscope*. 2016;126:1260-1266.
3. Melin M, Schwarz K, Lammers BJ, Goretzki PE. IONM-guided goiter surgery leading to two-stage thyroidectomy—indication and results. *Langenbecks Arch Surg*. 2013;398:411-418.
4. Schneider R, Randolph G, Dionigi G, et al. Prediction of postoperative vocal fold function after intraoperative recovery of loss of signal. *Laryngoscope*. 2019;129:525-531.
5. Schneider R, Randolph GW, Dionigi G, et al. International neural monitoring study group guideline 2018 part I: staging bilateral thyroid surgery with monitoring loss of signal. *Laryngoscope*. 2018;128(Suppl 3):S1-S17.
6. Sitges-Serra A, Fontané J, Dueñas JP, et al. Prospective study on loss of signal on the first side during neuromonitoring of the recurrent laryngeal nerve in total thyroidectomy. *Br J Surg*. 2013;100:662-666.
7. Dionigi G, Wu C-W, Kim HY, Rausei S, Boni L, Chiang F-Y. Severity of recurrent laryngeal nerve injuries in thyroid surgery. *World J Surg*. 2016;40:1373-1381.
8. Brauckhoff K, Svendsen ØS, Stangeland L, Biermann M, Aas T, Husby PJA. Injury mechanisms and electromyographic changes after injury of the recurrent laryngeal nerve: experiments in a porcine model. *Head Neck*. 2018;40:274-282.
9. Lee HY, Cho YG, You JY, et al. Traction injury of the recurrent laryngeal nerve: results of continuous intraoperative neuromonitoring in a swine model. *Head Neck*. 2016;38:582-588.
10. Schneider R, Przybyl J, Pliquett U, et al. A new vagal anchor electrode for real-time monitoring of the recurrent laryngeal nerve. *Am J Surg*. 2010;199:507-514.
11. Wu C-W, Dionigi G, Sun H, et al. Intraoperative neuromonitoring for the early detection and prevention of RLN traction injury in thyroid surgery: a porcine model. *Surgery*. 2014;155:329-339.
12. Brauckhoff K, Aas T, Biermann M, Husby P. EMG changes during continuous intraoperative neuromonitoring with sustained recurrent laryngeal nerve traction in a porcine model. *Langenbecks Arch Surg*. 2017;402:675-681.
13. Husby P, Heltne JK, Koller ME, et al. Midazolam-fentanyl-isoflurane anaesthesia is suitable for haemodynamic and fluid balance studies in pigs. *Lab Anim*. 1998;32:316-323.
14. Wu C-W, Liu X, Barczyński M, et al. Optimal stimulation during monitored thyroid surgery: EMG response characteristics in a porcine model. *Laryngoscope*. 2017;127:998-1005.
15. Barber SR, Liddy W, Kyriazidis N, et al. Changes in electromyographic amplitudes but not latencies occur with endotracheal tube malpositioning during intraoperative monitoring for thyroid surgery: implications for guidelines. *Laryngoscope*. 2017;127:2182-2188.
16. Brauckhoff K, Vik R, Sandvik L, et al. Impact of EMG changes in continuous vagal nerve monitoring in high-risk endocrine neck surgery. *World J Surg*. 2016;40:672-680.
17. Wu C-W, Dionigi G, Barczynski M, et al. International neuromonitoring study group guidelines 2018: part II: optimal recurrent laryngeal nerve management for invasive thyroid cancer-incorporation of surgical, laryngeal, and neural electrophysiologic data. *Laryngoscope*. 2018;128(suppl 3):S18-S27.
18. Dahle GO, Setså EJ, Svendsen ØS, et al. Vocal cord function during recurrent laryngeal nerve injury assessed by accelerometry and EMG. *Laryngoscope*. 2020;130:1090-1096.
19. Sitges-Serra A, Gallego-Otaegui L, Fontané J, Trillo L, Lorente-Poch L, Sancho J. Contralateral surgery in patients scheduled for total thyroidectomy with initial loss or absence of signal during neural monitoring. *Br J Surg*. 2019;106:404-411.
20. Randolph GW, Dralle H, International Intraoperative Monitoring Study Group, et al. Electrophysiologic recurrent laryngeal nerve monitoring during thyroid and parathyroid surgery: international standards guideline statement. *Laryngoscope*. 2011;121(suppl 1):S1-S16.
21. Fontenot TE, Randolph GW, Setton TE, Alsaleh N, Kandil E. Does intraoperative nerve monitoring reliably aid in staging of total thyroidectomies? *Laryngoscope*. 2015;125:2232-2235.
22. Phelan E, Schneider R, Lorenz K, et al. Continuous vagal IONM prevents recurrent laryngeal nerve paralysis by revealing initial EMG changes of impending neuropraxic injury: a prospective, multicenter study. *Laryngoscope*. 2014;124:1498-1505.