

Review Article



Standards for Intraoperative Neuromonitoring in Thyroid Operations

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ABSTRACT

After the introduction of intraoperative neural monitoring (IONM) of the recurrent laryngeal nerve (RLN) in clinical thyroid practice almost 16 years ago, the procedure has expanded rapidly with an area-wide spread in Asia, Europe, and USA. While the visual nerve presentation with the eye or the magnifying glass technique is capable of assessing the anatomical continuity of the RLN, IONM additionally allows a functional analysis that has a high correlation, i.e., prediction of postoperative vocal motility. Although the predictive value of the IONM is much higher (>97%) in the case of an intact signal than in the case of a signal failure (40%–70%), the prediction is also unequally higher than the visual-anatomical assessment of the nerve. Thus, IONM can be used as a basis for an intraoperative decision-making of a 1-side or 2-side procedure to avoid bilateral RLN palsy in a bilateral procedure. A precondition for the safe application of IONM is the perfect knowledge of the technology and technique, the routine execution of preoperative and postoperative laryngoscopy, the strict standardization of the neurostimulation (electromyography documentation of the vagal nerve stimulation before and after resection), and an adequate management of technically or operationally caused incidents (i.e., systematic application of troubleshooting algorithms). The following review provides a synopsis of the experiences of the Korean Intraoperative Neural Monitoring Society (KINMoS) for the correct use of IONM.

Keywords: Thyroid gland; General surgery; Recurrent laryngeal nerve; Nerve injury; Thyroidectomy

INTRODUCTION

Since the beginning of thyroid surgery, the surgical morbidity has been the focus of discussions [1-5]. Injury to the recurrent laryngeal nerve (RLN) is the leading cause of vocal cord paralysis associated with hoarseness, impaired vocal register, dysphonia, dysphagia, and aspiration [4,5]. After decades of debates about the prognosis of the laryngeal nerves, the conviction that thyroid gland resections in nerve proximity, i.e., total resection, visual nerve

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

identification, exposure, and presentation, are the best possible condition “gold standards” management for the RLN (**Table 1**) [6-13].

Previous studies reported a 0.4%–3.9% incidence of temporary RLN paralysis and a 0%–3.6% incidence of permanent RLN paralysis after thyroidectomy [6-13].

Intraoperative neuromonitoring (IONM) has been proposed as an adjunct to standard visual identification of the laryngeal nerves during thyroid surgery [14]. Technical advances currently allow accurate and noninvasive monitoring of the nerves [14]. With the availability of IONM, a new element has been introduced into the RLN management: the electromyographic (EMG) function of the nerve [14]. However, in order to enhance the outcomes of IONM on postoperative vocal cord function, the following prerequisites must be fulfilled:

1. Standardization of the technique, and specific experience and training with IONM device are essential for optimal use.
2. Correct functioning of the IONM equipment with regard to nerve stimulation “stimulation site” and the signal recording and reproducing “recording site.”
3. Intact and sufficient nerve conduction, including transfer into an adequate muscle action of the stimulated vocalis muscle.
4. Exclusion of pre-existing or endotracheal-induced non-nervous disorders of the vocal cord mobility.

So far, the results on the use of IONM have been discordant. For example, an IONM signal failure with postoperatively intact voice mobility, has been reported “right” on the one hand (i.e., loss of the nerve function with recovery of the nerve conduction at the time of the postoperative laryngeal examination, and “wrong” on the other hand (i.e., errors in the “stimulation” or “recording pattern” for intra- and postoperatively intact nerve function. This has led to an intensive discussion about the application of the IONM technology and its suitability for greater safety in the prevention of nerve damage [14,15].

In addition, it is understandable that both 1) a very strict standardization in the use of IONM and 2) a suitable “troubleshooting” in case of disturbances, i.e., signal failure, are necessary, while 3) the knowledge of the clinical larynx function (preoperative and postoperative laryngoscopy) must be evaluated, because the consequences of an intraoperative alteration of the primarily intended resection dimension (e.g., only unilateral rather than bilateral resection, “staged procedure”) and the necessary medico-legal expert assessment of an individual case can only be carried out correctly if the above mentioned conditions are met [15].

Table 1. Neural monitoring enhances the “gold standards” for RLN management in thyroid surgery

• Extensive knowledge of RLN anatomy
• Visual identification of RLN
• Exposure of RLN
• Experience and training
• Pre- and postoperative laryngoscopy

RLN = recurrent laryngeal nerve.

In addition to the technical aspects of RLN monitoring, it is currently clear that the available methods of intermittent or continuous nerve stimulation prevent the occurrence of RLN paresis in case of disturbances like traction or compression, but not RLN stress as a result of acute nerve injuries as in the case of a coagulation, ligation, or section [16-22].

Currently, it is clear from both experimental and clinical studies that the peculiarities of the nerve physiology of the RLN contain a gradual diminishing nervous function, e.g., during prolonged traction on the laryngeal nerve, with increased latency and decreased amplitude profile. Nevertheless, it is still not clear when and at what thresholds of amplitude and latency do these become irreversible [14,16-22].

STANDARDIZATION OF RLN MONITORING

Few surgeons have received formal training in using IONM. The Korean Intraoperative Neural Monitoring Society (KINMoS) offers and promotes continuous knowledge and training for the correct, systematic, and standard approach to IONM technique.

The standardization of intraoperative RLN monitoring is based on the following basic requirements (**Table 2**) [15]:

1. Preoperative and postoperative laryngoscopy and intraoperative EMG are inseparable units. The preoperative intraoperative EMG findings cannot be assessed without preoperative laryngoscopy findings. Similarly, the postoperative intraoperative EMG findings are also not possible to correlate without the postoperative laryngoscopy findings interpretation. Thus, preoperative and postoperative laryngeal examinations are a prerequisite for the clinical use of the IONM method. A preoperative laryngeal detection of RLN palsy must be interpreted with caution, because, in spite of paralyzed vocal motility, a nerve can still present with a positive EMG signal. Therefore, for the IONM, the following explanations refer to the situation of a preoperatively intact vocal laryngeal mobility, but not to the situation of a pre-existing vocal cord paresis.
2. The routine intraoperative check of the functional status of the IONM system to prove the concordance of preoperative vocal cord movement and neurostimulation. The correctness evaluation method requires nerve stimulation outside the potential operative area of the RLN. For this, the ipsilateral vagal stimulation is the safest. The results of the largest evaluation study carried out for this purpose clearly demonstrated the importance of this approach, i.e., pre-excision vagal nerve (VN) stimulation (**Fig. 1**) [15,23].

Table 2. The following standardized steps are required for the proper use of intraoperative RLN monitoring in clinical thyroid practice

- Preoperative assessment of the vocal cord function by laryngoscopy (L1)
- Use of modern audio and graphic IONM monitor software with documented latency and amplitude profile for the safe differentiation of artifact signals
- Verify meticulously the correct equipment installation, including placing the neutral and recording electrodes
- Use of short-acting muscle relaxants only during anesthesia initiation, renouncing this during the phase of the IONM
- Nerve stimulation with current amplitudes of 1–2 mA above the threshold current (0.3–0.8 mA)
- Ipsilateral stimulation of the vagus nerve with 1–2mA (above the threshold current intensity) and EMG recording before the start of the resection (V1)
- Visual presentation and ipsilateral stimulation of the RLN (R1)
- Post-resection ipsilateral stimulation of the VN (V2)
- Post-resection ipsilateral stimulation of the RLN (R2)
- Dispense the resection of the second side in the case of primarily planned bilateral procedure and loss of signal on the first side
- Postoperative assessment of the vocal cord function by laryngoscopy (L2)

RLN = recurrent laryngeal nerve; IONM = intraoperative neuromonitoring; EMG = electromyographic; VN = vagal nerve.

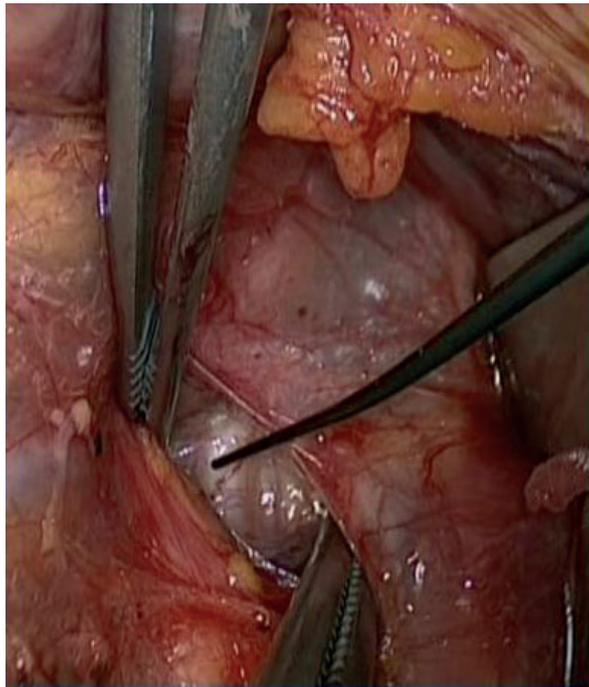


Fig. 1. Pre-dissection VN stimulation (V1).
VN = vagal nerve.

3. To achieve adequate nerve stimulation, the RLN and the VN should be stimulated beyond the threshold current of 0.3–0.8 mA. The optimal current strength for nerve stimulation is 1–2 mA. There is no further improvement and achievement of the muscle response of the vocalis muscle with a higher current strength [24].
4. Anesthesia management during intraoperative neuromonitoring does not require the use of muscle relaxants during the neuromonitoring phase, since these can impair the vocalis muscle response leading to intraoperative misinterpretations [25]. During induction anesthesia, the use of short-acting muscle relaxants (succinylcholine [Anectine[®]; Sandoz Inc., Princeton, NJ, USA] 2.0–2.5 mg/kg or rocuronium [Zemuron[™], Merck Canada Inc., Kirkland, Canada] or atracurium [Tracrium[®]; GlaxoSmithkline Pharmaceuticals Ltd., Mumbai, India] 0.5 mg/kg) is recommended in order to ensure adequate muscle activity when using nerve stimulation [25].
5. The correct IONM apparatus requires adequate placement of the cable connections, neutral electrodes, and EMG signal electrodes (i.e., needle electrodes or EMG endotracheal tube electrodes) (**Fig. 2**) [24]. When the needle electrodes are used, they must be inserted into the vocalis muscle separately for each of the operated sides [15,24]. When EMG endotracheal tube electrodes are used, it is necessary to ensure that the cuff of the tube is located below the glottal plane and the signal derivation electrodes above, i.e., in the glottal plane of the vocal folds, and not rotated after the patient has been positioned (**Fig. 3**) [24]. The proper contact of the EMG tube with the vocal cords is indicated by the following verification test: 1) impedance values readable on the IONM monitor less than 5 kΩ per electrode; 2) repeat laryngeal examination after the patient's head extension to check possible tube displacement; 3) respiratory variation; 4) tap test; and 5) intraoperative V1 above 500 mcV (**Table 3**) [24].

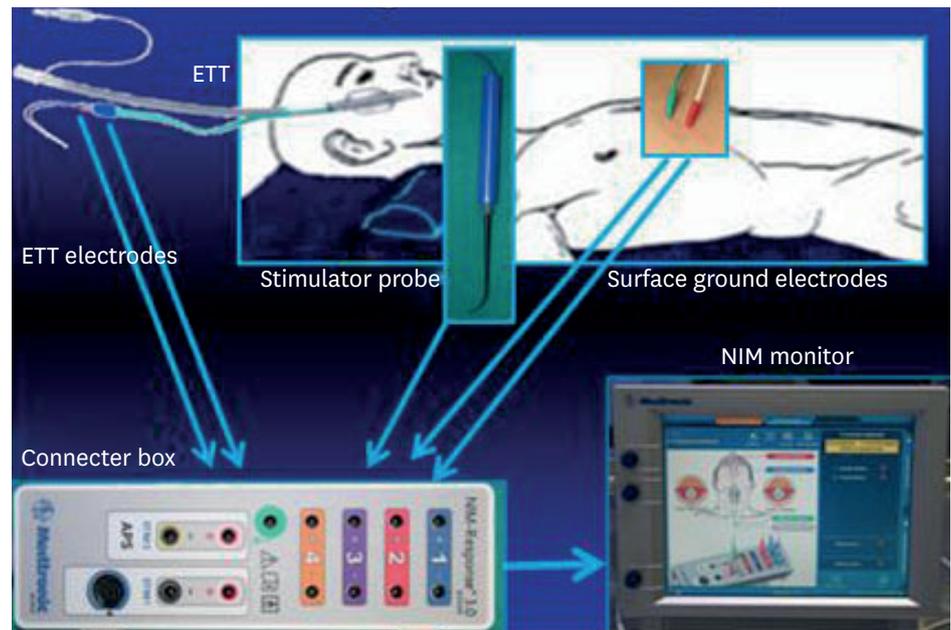


Fig. 2. Patient and EMG endotracheal tube scheme for IONM.

EMG = electromyographic; IONM = intraoperative neuromonitoring; ETT = endotracheal tube; NIM = nerve integrity monitor.

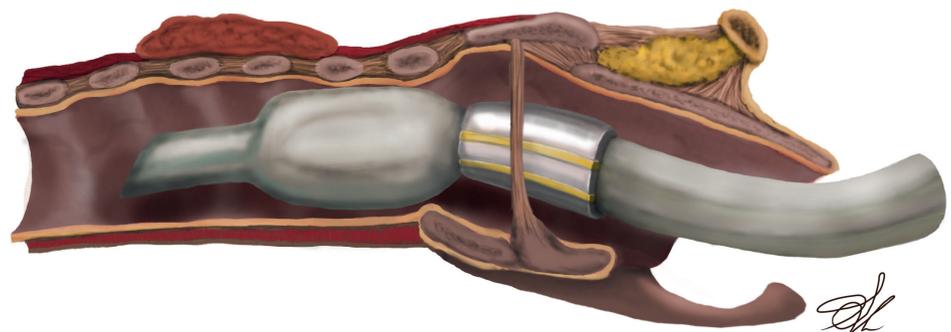


Fig. 3. When EMG endotracheal tube electrodes are used, it is to be ensured that the signal surface derivation electrodes are positioned in the glottal plane of the vocal folds and are not rotated after the patient has been stored. EMG = electromyographic.

Table 3. Verification test for proper contact of the EMG tube with the vocal cords

Preoperatively	<ol style="list-style-type: none"> 1) The impedance values readable on the IONM monitor, it should be less than 5 kΩ per electrode 2) Repeat laryngeal examination after patient head extension to check possible tube displacement 3) Respiratory variation 4) Tap test
Intraoperatively	<ol style="list-style-type: none"> 5) Achieve intraoperative V1 above 500 mcV 6) All above

EMG = electromyographic; IONM = intraoperative neuromonitoring.



Fig. 4. The use of audio and EMG signal equipment is recommended to enhance documentation of the stimulation EMG with quantification of latency and amplitude.
EMG = electromyographic.

Table 4. Unique features of audio and graphic IONM monitors for RLN monitoring

- Amplitude and latency profile recording
- Documentation
- Quantification
- Storage
- Differentiation between signal and artifact
- Forensic
- Research
- To justify surgical deliberations
- Record review and discussion at end of surgery

IONM = intraoperative neuromonitoring; RLN = recurrent laryngeal nerve.

6. The unequivocal determination of a regular nerve conduction and consecutive muscle action of the ipsilateral vocalis muscle requires qualitative and quantitative EMG recordings with amplitude and latency by the IONM device, since the sole signal sound reproduction cannot reliably distinguish between an artifact signal and a regular muscular action potential [15]. The use of modern audio and EMG signal equipment is recommended to enhance, if possible, the documentation of the stimulation EMG (**Fig. 4**) [15]. Not only does this allow a reliable detection of the muscle potential but the stimulation of the RLN or the VN provides a latency of the recurrent nerve and the vagus nerve significantly different from one another due to the different nerve lengths (**Table 4**) [15]. The different nerve lengths of the left and right nasal vagus also allow the respective EMG to be assigned to the right or left VN during stimulation of the vagus nerve for a secure lateral allocation [15,24].

TROUBLESHOOTING AND CONSEQUENCES FOR INTRAOPERATIVE SIGNAL LOSS

The definition of an intraoperative EMG signal loss (“loss of signal”, LOS) presupposes that the initial signal response was correct (**Table 5**). If the intraoperative signal fails or the EMG

Table 5. Definition of loss of EMG signal

• Normal vocal cord movement at preoperative laryngeal examination (L1)
• Initial satisfactory EMG signal (V1 >500 mcV)
• No EMG response with stimulation at 1–2 mA
• Low response <100 mcV with stimulation at 1–2 mA
• No laryngeal twitch
• Troubleshooting algorithm applied systematically

EMG = electromyographic.

drops below 100 μ V with a primary intact signal and adequate stimulation with 1–2 mA, a LOS must be assumed.

The IONM troubleshooting algorithm consists of the following steps in this sequence (**Fig. 5**):
 1) Exclusion of anesthesia-induced neuromuscular blockade, device-technical disturbances, dislocation of the neutral electrode or of the cable connections, tube dislocation, or dislocation of the surface electrodes. 2) Stimulation of the ipsilateral RLN before its entry into the larynx and stimulation of the ipsilateral VN; this is subsequently followed by verifying the stimulation

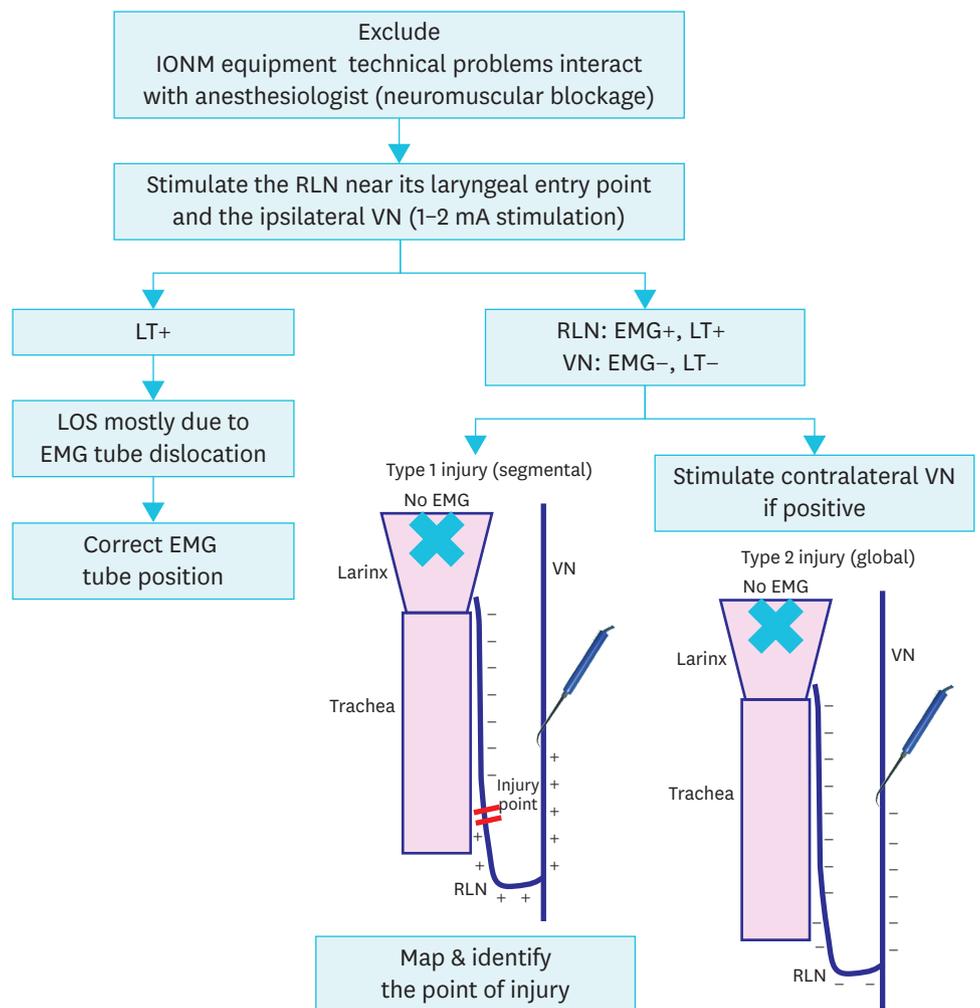


Fig. 5. Troubleshooting algorithm in case of loss of EMG signal. EMG = electromyographic.



Fig. 6. Laryngeal twitch.

response by means of EMG and possibly palpation of the dorsal larynx wall (laryngeal twitch) as a positive sign of an equilateral muscle action of the vocalis muscle (**Fig. 6**) [12].

Depending on the stimulation site and the stimulation response, the following conclusions can be drawn with regard to the main disorders of the ipsilateral RLN (**Fig. 5**):

1. Positive laryngeal twitch independent of the location of the stimulation: consider error of the "recording site," i.e., EMG endotracheal tube dislocation or needle dislocation. This necessitates a correction of the tube or needle electrode position in case of the use of needle electrodes.
2. A normal EMG and/or positive laryngeal twitch during stimulation of the RLN at the point of entry into the larynx, but a lack of an EMG response or missing laryngeal twitch when stimulating the vagus nerve: consider a real loss of function of the ipsilateral RLN. In this type of nerve disorder, the location of the nerve lesion can usually be localized by "mapping" (type 1, point/segmental injury, **Fig. 7**).
3. A lack of an EMG response and a missing laryngeal twitch regardless of the location of the stimulation (RLN or vagus nerve) means a diffuse nervous disorder (type-2 global injury, **Fig. 7**), assuming correct stimulation and exclusion of the causes mentioned above.
4. If there is any uncertainty regarding the function of the equipment, tube position, or position of the needle electrode, the contralateral VN should be stimulated. When the nerve function of the contralateral VN is intact, a disturbed nerve function can be assumed in the absence of a stimulation response from the side in question.

Discordant findings, i.e., neuromonitoring signal and EMG deviations from the postoperative vocal cord mobility, are extremely rare (<3%) with an intact neuromonitoring signal and EMG. In contrast, in the case of intraoperative signal failure, they are observed in about 30%–60%

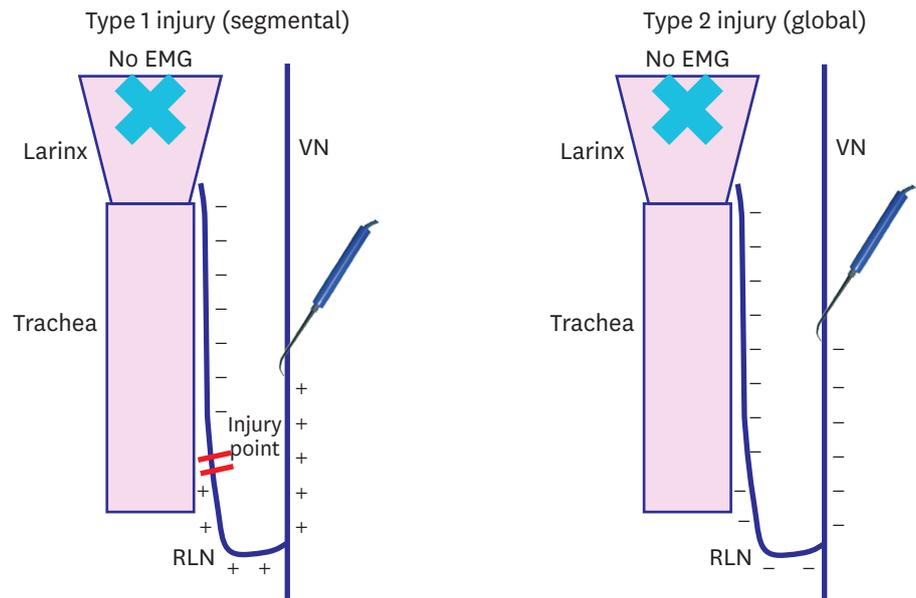


Fig. 7. Type 1 and type 2 injuries.

of the cases. Based on this, the surprising finding of a postoperative RLN palsy is extremely rare with intraoperatively intact signal and EMG. In the case of intraoperative signal failure, however, postoperative RLN palsy is expected at only 30%–60%.

Due to the significantly higher predictive significance of intraoperative EMG with respect to the postoperative vocal cords compared to the visual-anatomical assessment alone after resection of a signal failure first side, if the first side of a planned 2-sided resection is concerned, it should be not recommended to remove the contralateral side in order to avoid the risk of bilateral vocal cord palsy. In bilateral benign goiter and most low-risk carcinomas, there is generally no need for resection of the contralateral side in case of intraoperative signal loss on the first side. The laryngoscopy on the first postoperative day reveals whether or not an RLN palsy is present on the disturbed side; if not, the resection of the second side can be made immediately or, depending on the urgency of the situation, at a later date [16-29].

CONCLUSIONS AND ASSESSMENTS IN CASE OF RLN INJURY

Most of the multicentric retrospective studies and prospective randomized studies have reported a decrease in the RLN palsy rate using IONM vs. the “gold standard” of the visual nerve identification only, but the difference between the two techniques was not statistically significant [2,30,31].

An low surgical experience has been associated with a lower palsy rate when IONM is used [30,31].

Since not only high risk interventions but also atypical RLN variants and locations are associated with a demonstrable increase in RLN palsy risk in primary procedures, it is to be assumed that neuromonitoring is also advantageous in such situations due to a better RLN prognosis [32].

In recent years, the expert assessment of intraoperative neuromonitoring has repeatedly led to the assessment of RLN paresis in cases of damage; IONM guidelines for the proper use of intraoperative neuromonitoring are now published [24].

The position of the surgical expert in such cases is not easy because the correct assessment of the individual case requires not only experience with neuromonitoring but also, at least, a certain degree of traceability of the use of this method in the given case, i.e., a corresponding EMG documentation of neurostimulation in order to draw justifiable conclusions from a surgical perspective.

Currently, the following observations can be made for the expert assessment of intraoperative neuromonitoring on the basis of the above-described advantages and limitations of this method:

1. When intraoperative neuromonitoring is used, the following points should be considered: 1) compliance with the standards set-up (**Table 2**) and 2) systematic use of troubleshooting algorithms in the case of intraoperative signal loss (**Fig. 5**). Both points are essential for a correct interpretation of intraoperative EMG signals and, in the case of intraoperative signal loss, to draw appropriate conclusions.
2. Since the signal tone alone does not differ sufficiently reliably between artifact and regular muscle action potential, the simultaneous EMG recording alone represents the “gold standard” of the nerve function assessment. The only and best documentation currently available for an expert assessment of the intraoperative nerve function state is the EMG expression of ipsilateral vagal stimulation before and after resection.
3. The sensitivity of intraoperative neuromonitoring with regard to the assessment that postoperative RLN paresis follows an intraoperative signal failure is still unsatisfactory. Nevertheless, the intraoperative signal failure represents the best currently available technique, significantly superior risk criterion vs. the only anatomical-visual assessment for the prediction of a postoperative recurrence paresis. Thus, in case of a signal loss on the first operated side within an intended bilateral procedure the resection of the second side should be dispensed in the same session until the recovery of the nerve in order to avoid the risk of bilateral recurrent palsy. The reason for the premature bilateral resection in this situation has to be linked to high-threshold conditions, since there are very few indications under which the resection of the contralateral side could not occur at a later time.
4. Preoperative patient information (informed consent) should adequately take into account this neuromonitoring-dependent procedural strategy by informing the patient that intraoperative signal failure of the first operated side is generally dispensed with a 2-step procedure for the sake of avoiding 2-way RLN paresis more safely.

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