



RESEARCH

Mechanism-dependent outcomes of recurrent laryngeal nerve injury after thyroidectomy with intermittent intraoperative nerve monitoring

Aralıklı intraoperatif sinir monitörizasyonu eşliğinde tiroidektomi sonrası rekürren laringeal sinir yaralanmasının mekanizmaya bağlı sonuçları

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Abstract

Purpose: This study aimed to evaluate the etiology and functional outcomes of recurrent laryngeal nerve (RLN) injury in patients with intraoperative loss of signal (LOS) verified by postoperative laryngoscopy.

Materials and Methods: This retrospective cohort study analyzed 1840 patients (3159 nerves at risk (NAR)) who underwent thyroid surgery at a high-volume tertiary center between 2020 and 2025, with routine use of intermittent intraoperative nerve monitoring (I-IONM) and selective postoperative laryngoscopic assessment. Intraoperative LOS events were classified by presumed injury mechanism, and vocal cord paralysis (VCP) outcomes were evaluated at 6 months.

Results: LOS verified by postoperative laryngoscopy occurred in 114 patients (6.2% per patient; 3.6% per NAR). Transient and permanent VCP rates were 4.3% and 1.7% per patient, respectively. Traction was the most frequent injury mechanism (64%), followed by compression (19.3%) and transection (11.4%). Recovery was strongly dependent on injury mechanism: 79.5% of traction-related and 72.7% of compression-related injuries resulted in transient VCP (T-VCP), whereas 92.3% of transection injuries led to permanent VCP (P-VCP).

Conclusion: While I-IONM does not reliably prevent RLN injury, it provides clinically actionable information that guides intraoperative strategy and mechanism-based prognostic stratification. Integration of electrophysiologic findings with postoperative laryngoscopy supports informed decision-making and risk mitigation in contemporary thyroid surgery.

Keywords: Recurrent laryngeal nerve, vocal cord paralysis, intraoperative nerve monitoring

Öz

Amaç: Bu çalışma, ameliyat sonrası laringoskopi ile doğrulanmış intraoperatif sinyal kaybı (LOS) olan hastalarda rekürren laringeal sinir (RLN) hasarının etiolojisini ve fonksiyonel sonuçlarını değerlendirmek amacıyla yapılmıştır.

Gereç ve Yöntem: Bu retrospektif kohort çalışmasında, 2020–2025 yılları arasında yüksek volümlü üçüncü basamak bir merkezde tiroidektomi uygulanan 1840 hasta (risk altındaki sinir sayısı: 3159) analiz edildi. Tüm olgularda rutin aralıklı intraoperatif sinir monitörizasyonu (I-IONM) kullanıldı ve postoperatif laringoskopik değerlendirme selektif olarak yapıldı. LOS olayları olası yaralanma mekanizmasına göre sınıflandırıldı ve vokal kord paralizisi (VKP) sonuçları 6. ayda değerlendirildi.

Bulgular: Postoperatif laringoskopi ile doğrulanan LOS 114 hastada saptandı (%6,2 hasta bazlı; %3,6 sinir bazlı). Geçici ve kalıcı VKP oranları hasta bazında sırasıyla %4,3 ve %1,7 idi. En sık yaralanma mekanizması traksiyon (%64) olup bunu kompresyon (%19,3) ve kesilme (%11,4) izledi. İyileşme yaralanma mekanizmasına güçlü biçimde bağlıydı: traksiyon ilişkili yaralanmaların %79,5'i ve kompresyon ilişkili yaralanmaların %72,7'si geçici VKP ile sonuçlanırken, kesilme yaralanmalarının %92,3'ü kalıcı VKP ile sonuçlandı.

Sonuç: I-IONM RLS yaralanmasını güvenilir biçimde önlemese de intraoperatif stratejiyi yönlendiren ve mekanizma temelli prognostik sınıflama sağlayan klinik olarak uygulanabilir bilgiler sunar. Elektrofizyolojik bulguların postoperatif laringoskopi ile birlikte değerlendirilmesi, güncel tiroid cerrahisinde bilinçli karar verme ve risk azaltımını desteklemektedir.

Anahtar kelimeler: Rekürren laringeal sinir, vokal kord paralizisi, intraoperatif sinir monitörizasyonu

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INTRODUCTION

Thyroidectomy is one of the most frequently performed endocrine surgical procedures and is generally associated with low morbidity when conducted by experienced surgeons. Nevertheless, recurrent laryngeal nerve (RLN) injury remains one of the most concerning complications of thyroid surgery, as it may lead to transient or permanent vocal cord paralysis (VCP)¹. Postoperative VCP can result in hoarseness, dysphagia, aspiration, dyspnea, and, in bilateral cases, life-threatening airway compromise. Beyond functional morbidity, RLN injury significantly affects quality of life and continues to represent a major source of medicolegal claims following thyroidectomy^{2,3}.

The reported incidence of VCP after thyroidectomy varies widely in the literature, with transient paralysis occurring in approximately 2–14% of patients and permanent paralysis in 0.3–3%, depending on patient characteristics, surgical indication, extent of surgery, and surgeon experience^{4,5}. Several clinical and surgical factors have been consistently associated with an increased risk of RLN injury, including thyroid malignancy, Graves' disease, large or substernal goiters, reoperative surgery, and central neck dissection^{6,7}. Importantly, contemporary studies have demonstrated that most RLN injuries are not caused by complete nerve transection but rather by traction, compression, thermal injury, or inadvertent ligation, mechanisms that may leave the nerve anatomically intact while causing functional impairment^{8,9,10}.

Intraoperative nerve monitoring (IONM) has been introduced as an adjunct to visual identification of the RLN, providing functional information during thyroid surgery. Intermittent intraoperative nerve monitoring (I-IONM) remains the most commonly used modality in routine clinical practice because of its technical simplicity and widespread availability. However, the effectiveness of I-IONM in reducing postoperative VCP remains controversial in the literature. Recent retrospective cohort studies and meta-analyses have reported conflicting results, with some demonstrating a reduction in transient RLN injury, while others have shown no significant difference in overall or permanent VCP (P-VCP) rates compared with visual nerve identification alone^{11,12,13,14}. These inconsistencies are likely related to heterogeneity in study design, patient selection,

surgeon experience, and the inherently low incidence of permanent RLN injury, which limits statistical power in retrospective analyses. Beyond its potential preventive role, I-IONM offers a unique opportunity to identify the timing and mechanism of RLN injury during surgery. Detection of loss of signal (LOS) or signal deterioration may help clarify whether postoperative VCP is related to traction, compression, thermal injury, or direct nerve damage, and may provide valuable prognostic information regarding nerve recovery^{15,16}.

This study aimed to evaluate the etiology and functional outcomes of RLN injury in patients with intraoperative LOS verified by postoperative laryngoscopy within a large thyroidectomy cohort, to analyze intraoperative etiological mechanisms of nerve injury identified using I-IONM, and to determine the proportion of T-VCP and P-VCP according to the underlying etiology in a single-center surgical cohort. We hypothesized that specific mechanisms of RLN injury are associated with distinct postoperative outcomes and that traction-related injuries predominantly result in transient paralysis, whereas direct nerve damage is more likely to lead to permanent vocal cord dysfunction.

MATERIALS AND METHODS

Study design

This study was designed as a retrospective observational cohort study conducted at a high-volume tertiary referral center with a dedicated endocrine surgery unit. Patients treated between June 2020 and May 2025 in the Endocrine Surgery Unit of the Department of General Surgery, Basaksehir Cam and Sakura City Hospital, Istanbul, were evaluated. No artificial intelligence–assisted tools were used in the design, analysis, or writing of this study. No a priori sample size calculation was performed due to the retrospective observational design. The study cohort comprised all consecutive thyroidectomy patients with intraoperative LOS during the study period who met the inclusion criteria.

Sample

All patients who underwent thyroid surgery during the study period were prospectively recorded in an institutional database and retrospectively analyzed. All consecutive patients who underwent thyroid and parathyroid surgery at our institution between June

2020 and May 2025 were screened for eligibility. During this period, 2,378 patients were assessed. Patients who underwent surgery exclusively for parathyroid disease (primary or recurrent hyperparathyroidism, secondary or tertiary hyperparathyroidism, or MEN-related parathyroid disease; n = 495), isolated lateral neck procedures for recurrent disease without thyroidectomy (n = 39), or intentional recurrent laryngeal nerve (RLN) resection due to tumor invasion (n = 4) were excluded. After exclusions, 1,840 patients who underwent thyroid surgery constituted the study population. Patients were eligible for inclusion in the analytic cohort if

they experienced intraoperative loss of signal (LOS) during thyroidectomy and had postoperative laryngoscopic confirmation of vocal cord dysfunction. A total of 114 patients met these criteria and were included in the final analysis. Patients without intraoperative LOS or without postoperative laryngoscopic verification were not included in the LOS cohort. The numerical patient flow and exclusion reasons are presented in the Figure 1. In these patients, demographic and clinical characteristics, surgical indications, surgery type, presumed etiology of RLN injury, and vocal cord outcomes were systematically evaluated.

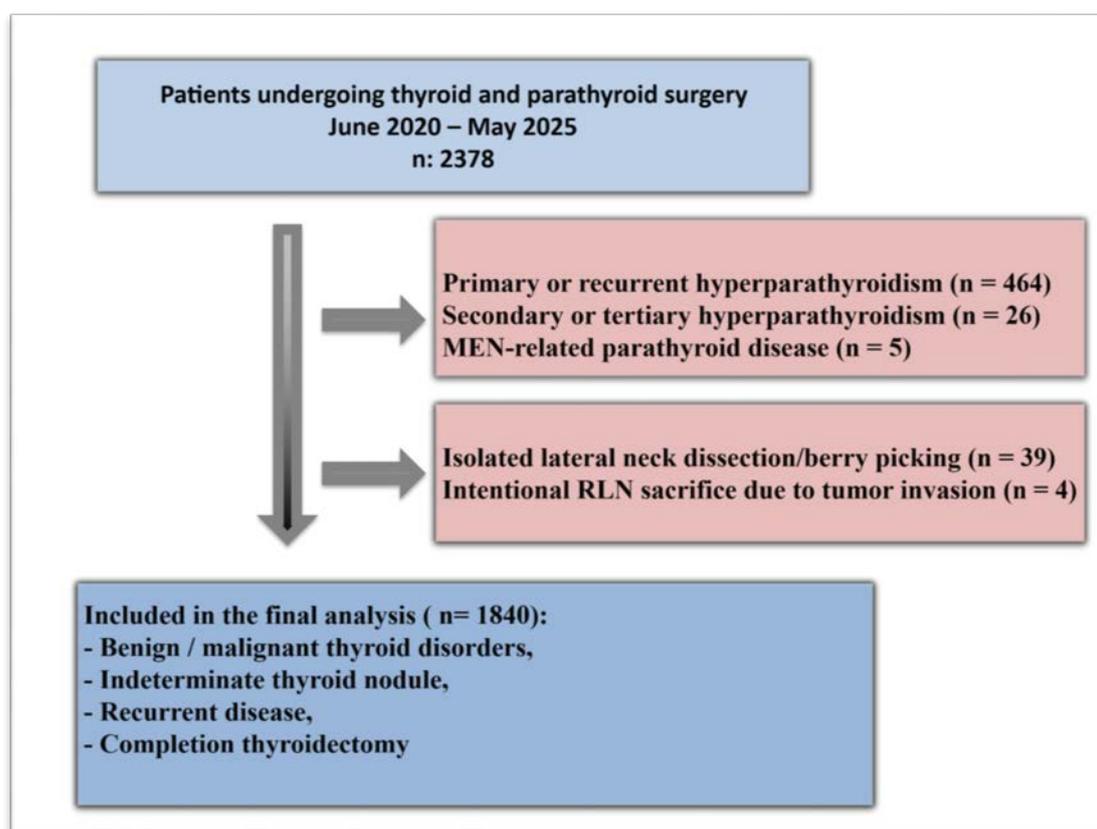


Figure 1. Flow diagram illustrating, exclusion criteria, and final study group allocation.

Procedure

The study protocol was reviewed and approved by the Basaksehir Cam and Sakura City Hospital Ethics Committee (Approval No: KAEK/05.02.2025.40, Approval Date: 10.02.2025) and the study was

conducted in accordance with the principles of the Declaration of Helsinki. Due to the retrospective nature of the study and the use of anonymized data, the requirement for informed consent was waived by the Ethics Committee.

Preoperative assessment

All patients underwent routine preoperative fiber nasopharyngolaryngoscopic examination to document baseline vocal cord mobility and to exclude pre-existing VCP. Standard preoperative evaluation included neck ultrasonography, fine-needle aspiration cytology when indicated, cross-sectional imaging in selected advanced or recurrent cases, measurement of serum thyroid function tests and calcitonin.

Surgical technique and intraoperative neuromonitoring

Thyroidectomy procedures were performed by five experienced endocrine surgeons. Preoperative and postoperative vocal cord examinations were carried out by otolaryngologists in the otorhinolaryngology department. Intraoperative neuromonitoring and LOS classification were performed and recorded by the operating surgeons, who also conducted the final data verification and analysis. All procedures were performed under general anesthesia using short-acting neuromuscular blocking agents.

Thyroid surgery was carried out according to standard capsular dissection principles with systematic identification of the RLN. Intermittent intraoperative nerve monitoring was routinely used in all patients, in accordance with the recommendations of the International Neural Monitoring Study Group (INMSG)¹³. Neuromonitoring was performed using a nerve monitoring system with electromyographic endotracheal tubes (Medtronic, Jacksonville, FL, USA). Standardized stimulation and recording protocols were applied throughout the procedure. For I-IONM, a monopolar stimulator probe (Medtronic Xomed) was used. The stimulation was applied with a current intensity of 1 mA, the stimulation duration of 100 ms, the threshold value of 100mV, and the current frequency of 4 Hz. In cases of technical problems related to the monitoring system, including signal loss attributable to endotracheal tube displacement or equipment malfunction, a troubleshooting algorithm was applied according to INMSG guidelines¹³. If adequate signal quality could not be restored after standard corrective measures, intraoperative neuromonitoring was continued using a needle electrode to ensure functional nerve assessment throughout the remainder of the procedure. When intraoperative transection of the RLN was identified, the proximal and distal nerve ends were meticulously prepared,

and a tension-free end-to-end anastomosis was performed.

Definitions

Loss of Signal (LOS): Loss of signal was defined as a decrease in amplitude below 100 μ V or failure to receive it with supramaximal stimulation despite appropriate stimulation parameters, after excluding technical causes, in accordance with INMSG criteria¹³.

Transient vocal cord paralysis: Transient VCP (T-VCP) was defined as postoperative vocal cord immobility or hypomobility that recovered within 6 months after surgery.

Permanent vocal cord paralysis: Permanent VCP (P-VCP) was defined as persistent absence of vocal cord movement beyond 6 months of follow-up. These definitions were consistent with contemporary literature and international neuromonitoring guidelines.

Postoperative evaluation and follow-up

Postoperative laryngoscopic evaluation was selectively performed in patients with intraoperative LOS or suspected signal deterioration. Patients without intraoperative signal abnormality and with preserved V2 response did not undergo routine postoperative laryngoscopy. Therefore, detailed etiologic and prognostic analyses in this study were confined to LOS-verified patients.

Postoperative fiber-optic nasopharyngolaryngoscopic examination was performed on postoperative day 1 in patients with intraoperative LOS or suspected signal deterioration. Vocal cord mobility was assessed and documented in all cases.

In patients who developed postoperative VCP: The etiology and type of nerve injury (e.g., traction, compression, thermal injury, or transection) were recorded intraoperatively when LOS occurred. The presumed mechanism of RLN injury was recorded intraoperatively at the moment of LOS based on the surgical maneuver being performed and the visual status of the nerve. Traction injury was defined as signal deterioration occurring during medial thyroid lobe retraction or capsular dissection with an anatomically intact nerve subjected to longitudinal tension. Compression injury was defined as signal loss associated with focal mechanical pressure, clamping, or tissue entrapment of the nerve without

structural disruption. Transection, ligation, and thermal injury were defined by direct visual confirmation of structural discontinuity or energy-related damage. The presumed mechanism was recorded intraoperatively in operative reports at the time of LOS and subsequently verified during data review.

Patients with documented VCP were followed longitudinally. A follow-up laryngoscopic examination at or beyond 6 months postoperatively was performed retrospectively in all patients with VCP to determine recovery status and to classify paralysis as transient or permanent.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 27.0; IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Kolmogorov–Smirnov test. Normally distributed variables were expressed as mean \pm standard deviation (SD), while non-normally distributed variables were presented as median (interquartile range, IQR). Categorical variables were summarized as frequencies and percentages. Demographic and clinical characteristics, including age, sex, preoperative diagnosis, type of surgery, and surgical indications, were analyzed descriptively. The incidence of postoperative VCP was calculated, and cases were further categorized according to the etiology of RLN injury (e.g., traction, compression, thermal injury, or direct nerve damage). The proportion of patients with recovery of vocal cord mobility at the 6-month follow-up was calculated, and differences between transient and permanent VCP were evaluated.

RESULTS

A total of 1840 patients underwent thyroid surgery for various benign and malignant thyroid diseases during the study period. Surgical indications and underlying diagnoses are summarized below. Among patients operated on for thyroid hormone-related disorders, Graves' disease was the most frequent indication, accounting for 160 patients, followed by toxic multinodular goiter (MNG) in 113 patients and toxic adenoma in 27 patients. Regarding nodular thyroid disease, 382 patients underwent surgery either for indeterminate solitary thyroid nodules (Bethesda III or IV) or subsequently required completion thyroidectomy for therapeutic purposes after

histopathological evaluation. Surgery was performed for MNG in 467 patients, while 51 patients underwent reoperation for recurrent MNG. Malignant thyroid disease represented a significant portion of the study population. A total of 513 patients underwent surgery due to preoperative suspicion of malignancy or malignancy corresponding to Bethesda category V–VI. Medullary thyroid carcinoma was identified in 39 patients. In addition, locoregional metastatic papillary thyroid carcinoma requiring surgical intervention was present in 88 patients, all of whom underwent extended surgical procedures. Regarding extent of surgery, total thyroidectomy (TT) was performed in 1319 patients and hemithyroidectomy in 521 patients. Overall, 3159 recurrent laryngeal nerves at risk (NAR) were evaluated intraoperatively. Baseline demographic and clinical characteristics of LOS cases are summarized in table 1.

Within the overall thyroid surgery cohort, LOS verified by postoperative laryngoscopic examination, corresponding to VCP, was identified in 114 patients. Incidence rates are therefore reported on both a patient-based ($n=1.840$) and NAR-based ($n=3.159$) denominator. These LOS events corresponded to an incidence of 6.2% per patient ($114/1.840$) and 3.6% per NAR ($114/3.159$). In 52 patients (45.6%) with LOS on the affected side, the procedure was staged and not continued intraoperatively, whereas surgery was completed in 62 cases (54.4%).

In the 114 LOS-verified cases, the cohort included 93 females (81.6%) and 21 males (18.4%), with a mean age of 44.9 ± 13.1 years (median 44). Operative procedures, LOS characteristics and injury etiology are summarized in Table 2. LOS occurred more frequently on the left RLN ($n=65$) than the right RLN ($n=49$). According to LOS classification, Type I LOS was observed in 37 cases (32.5%) and Type II LOS in 77 cases (67.5%). Etiology of injury in LOS cases was most commonly attributed to traction ($n=73$, 64.0%), followed by compression-type injury ($n=22$, 19.3%), transection ($n=13$, 11.4%), ligation ($n=4$, 3.5%), and thermal injury ($n=2$, 1.8%).

Among the 114 patients with VCP, six-month follow-up laryngoscopic outcomes were available in 111 patients (97.4%), while 3 patients (2.6%) were lost to follow-up and could not undergo long-term assessment. At six months, T-VCP with recovery of mobility was observed in 80 patients, whereas P-VCP was observed in 31 patients, corresponding to 72% transient and 28% permanent paralysis among

patients with available follow-up. Within the entire thyroidectomy cohort, P-VCP occurred in 31 patients, corresponding to a patient-based rate of 1.7% (31/1.840) and a NAR based rate of 0.98% (31/3.159).

Table 1. Baseline demographic and clinical characteristics of LOS cases (n:114)

Variables	Mean±SD*	Median (Min-Max)
Age (year)	44.9 ± 13.1	44 (21-78)
	Number (n)	Percentage (%)
Female sex	93	81.6
Male sex	21	18.4
Preoperative Diagnosis		
Multinodular goiter / Recurrent multinodular goiter	34	29.8
Toxic multinodular goiter	5	4.4
Graves' disease	11	9.6
Indeterminate solitary thyroid nodule	12	10.5
Suspicion for malignancy or malignancy	47	41.2
Locoregional metastatic papillary thyroid cancer	4	3.5
Medullary thyroid cancer	1	0.9
Surgical procedure		
Hemithyroidectomy	35	30.7
Hemithyroidectomy + unilateral CND **	16	14
Hemithyroidectomy + unilateral CND + unilateral/bilateral SND ***	2	1.8
Total thyroidectomy	40	35.1
Total thyroidectomy + unilateral/bilateral CND	18	15.8
Total thyroidectomy + unilateral/bilateral CND + unilateral/bilateral SND	3	2.6
Side of affected RLN †		
Right	49	43
Left	65	57
Type of LOS §		
Type I	37	32.5
Type II	77	67.5

*SD, standard deviation, **CND, central neck dissection; ***SND, selective neck dissection; †RLN, recurrent laryngeal nerve; § LOS, loss of signal; Values are presented as n (%); Percentages were calculated using the denominator of LOS-verified patients (n=114).

Table 2. Etiology of RLN injury in patients with LOS (n=114) and vocal cord outcomes (n = 111)

Etiology of RLN† injury*	n (%) (n=114)	Vocal cord outcomes according to etiology**	
		Transient VCP§ n (%), (n=111)	Permanent VCP n (%), (n=111)
Traction	73 (64)	58 (79.5)	13 (17.8)
Compression	22 (19.3)	17 (77.3)	4 (18.2)
Transection	13 (11.4)	1 (7.7)	12 (92.3)
Ligation	4 (3.5)	2 (50.0)	2 (50.0)
Thermal	2 (1.8)	2 (100)	0 (0)
TOTAL	114 (100)	80 (72)	31 (28)

† RLN, recurrent laryngeal nerve; § VCP, vocal cord paralysis; Values are presented as n (%), *Percentages were calculated using the denominator of LOS-verified patients (n=114); **Percentages for VCP outcome were calculated using the denominator of patients with available follow-up (n=111).

When 6-month outcomes were analyzed according to the etiology of RLN injury, distinct recovery patterns were observed. Among patients with traction-related injury (n = 73), 58 patients demonstrated T-VCP (79.5%). In patients with compression-related injury (n = 22), 17 cases resulted in T-VCP (77.3%). Ligation-related injury was identified in 4 patients,

with 2 patients experiencing T-VCP (50%). All patients with thermal injury–related VCP showed complete recovery at follow-up. In contrast, among patients with transection-related injury, 12 patients developed P-VCP, while only 1 patient (7.7%) demonstrated recovery at six months. The

distribution of transient and permanent VCP according to injury etiology is detailed in Table 2.

DISCUSSION

Recurrent laryngeal nerve dysfunction remains one of the most feared complications of thyroid surgery because it directly affects phonation, swallowing safety, and airway protection, and continues to be a major driver of patient dissatisfaction and medicolegal burden^{3,17}. Contemporary literature still reports a wide range of postoperative VCP rates, reflecting heterogeneity in indications (benign vs malignant disease), extent of dissection (including CND/SND), risk profile (reoperation, Graves' disease, retrosternal goiter), and critically on how systematically postoperative laryngoscopy is performed^{18,19}. Moreover, consensus statements emphasize that most RLN dysfunctions occur despite an anatomically intact nerve and are commonly related to traction, compression, thermal spread, or inadvertent ligation rather than complete transection, underscoring the need to better understand injury mechanisms and their prognostic implications in real-world practice¹. In this context, IONM has increasingly been used as an adjunct to visual identification; however, the core controversy persists: while IONM may enhance intraoperative decision-making, its ability to prevent RLN injury remains inconsistent across studies^{4,11,14}.

In this single-center retrospective series, we evaluated functionally verified RLN injury by combining intraoperative electrophysiologic findings with postoperative laryngoscopic confirmation in patients with LOS. Within a large thyroid surgery cohort, LOS verified by postoperative laryngoscopy and corresponding VCP occurred in 6.2% per patient and 3.6% per NAR, and P-VCP rate was 1.7% per patient; 0.98% per NAR. These rates are consistent with contemporary literature. Reviews commonly report P-VCP rates of approximately 0.3–3% with transient palsy around 5–8%, varying by case mix, surgical extent, and follow-up definitions^{20, 21}. In addition, recent overviews summarizing large datasets report mean incidences of transient and permanent VCP around 9.8% and 2.3%, respectively²².

A growing body of evidence indicates that most RLN injuries during thyroid surgery result from functional impairment rather than complete nerve transection, with traction, compression, thermal spread, and vascular compromise being the predominant

mechanisms. The traction mechanism has been identified, particularly during medial thyroid lobe retraction and Berry's ligament dissection, as the leading cause of RLN injury^{12,23}. In a large prospective clinical series analyzing 281 electrophysiologically confirmed RLN injuries detected using IONM, Dionigi et al. demonstrated that traction injury accounted for approximately 71% of all RLN injury events, whereas thermal injury (17%), compression (4.2%), and direct nerve disruption represented substantially smaller proportions. Importantly, traction-related injuries were most frequently observed during medial thyroid lobe retraction and dissection in the region of Berry's ligament²⁴. Similarly, Liu et al., in a retrospective cohort of 2,257 patients encompassing 3,582 NAR, specifically evaluated RLN injuries occurring near the nerve entry point into the larynx and reported that traction was responsible for 52.6% of injuries, followed by compression in 38.8%, while thermal and transection-related mechanisms were relatively uncommon²⁵. In our cohort, traction accounted for nearly two-thirds of injuries, mirroring the mechanistic distribution emphasized in recent mechanistic studies and reinforcing traction control as a prime target for surgical strategy optimization. Notably, prospective electrophysiologic studies have shown that EMG amplitude can decline across defined intraoperative time points, providing indirect support for the idea that many injuries occur during mobilization and medialization maneuvers rather than at a single catastrophic moment¹⁰. Moreover, international multicenter prospective work has emphasized that anatomic variability in RLN course is associated with increased dysfunction risk, further supporting the role of traction and mechanical vulnerability as dominant contributors to RLN morbidity in routine thyroidectomy⁸.

The most clinically actionable finding of the present study is the clear and consistent association between injury mechanism and postoperative prognosis. In a large clinical analysis of 281 electrophysiologically confirmed RLN injury events, Dionigi et al. reported an overall functional recovery rate exceeding 90%, with traction-related injuries exhibiting significantly faster and more complete recovery compared with other mechanisms, supporting a neurapraxia-dominant injury pattern²⁴. Similarly, Liu et al., analyzing a broad retrospective cohort of 2,257 patients suggested that mechanical injuries were associated with more favorable functional restoration, whereas non-mechanical mechanisms

carried a higher risk of delayed or incomplete recovery²⁵. Extending these observations, emerging clinical evidence has highlighted the prognostic value of intraoperative electrophysiology beyond a binary LOS classification. In a recent cohort study, Gallucci et al. demonstrated that partial intraoperative signal recovery after LOS was strongly associated with normal postoperative vocal cord motility, underscoring the importance of dynamic signal assessment for outcome prediction¹⁶. In line with these reports, our findings demonstrate a parallel mechanism-dependent gradient, with traction- and compression-related injuries showing high rates of T-VCP (79.5% and 77.3%, respectively), while transection was associated with P-VCP in 92.3% of cases, reinforcing that injury mechanism is a key determinant of postoperative recovery.

There is an ongoing debate regarding the preventive efficacy of I-IONM. Recent high-volume systematic reviews and meta-analyses consistently indicate that I-IONM does not reliably reduce temporary or permanent RLN injury rates compared with visual identification alone, particularly when rigorous laryngoscopic confirmation is required^{4,11,14}. For instance, Cozzi et al., analyzing endoscopic outcomes from more than 73,325 NAR, demonstrated overlapping pooled rates of temporary and definitive RLN injury between monitored and non-monitored procedures, concluding that IONM did not meaningfully alter overall injury risk⁴. Meta-analyses focusing on randomized controlled trials similarly emphasize that any preventive effect, especially for P-VCP, is difficult to demonstrate given its low baseline incidence and the heterogeneity of case mix and surgeon experience, a view further supported by large retrospective cohorts showing that surgical expertise and operative complexity may outweigh the independent effect of IONM use^{11,12}.

Rather than re-examining preventive efficacy, our data reinforce a more defensible and clinically relevant interpretation of I-IONM: its value lies in real-time functional assessment that enables early recognition of LOS, identification of injury mechanism, and informed intraoperative decision-making. In this regard, guideline-based responses to LOS particularly the adoption of staged thyroidectomy to avoid bilateral VCP represent one of the clearest practical benefits of neuromonitoring in daily practice¹³. In our cohort, 45.6% of verified LOS events led to staging, closely aligning with INMSG recommendations and contemporary

studies highlighting LOS as a trigger for risk-mitigating strategy modification rather than merely a technical event^{13,15}.

Beyond surgical strategy, I-IONM provides prognostically meaningful information. Contemporary evidence demonstrates that dynamic electrophysiologic behavior carries predictive value: Gallucci et al. reported that partial intraoperative signal recovery after LOS was strongly associated with normal postoperative vocal cord mobility, underscoring the limitations of a binary “signal/no signal” interpretation¹⁶. Similarly, international surveys and guidance documents emphasize that the characteristics of LOS carry important clinical implications beyond intraoperative documentation. In particular, Schneider et al., on behalf of the INMSG, highlighted that confirmed LOS should prompt not only structured intraoperative troubleshooting and consideration of staged thyroidectomy, but also mechanism-informed postoperative counseling and tailored follow-up strategies, given the variable recovery potential associated with different injury patterns¹³. In line with this perspective, international practice surveys summarized by Huang et al. demonstrated that a substantial proportion of endocrine surgeons incorporate LOS characteristics such as presumed mechanism, completeness of signal loss, and intraoperative signal recovery into their expectations regarding postoperative vocal cord recovery and surveillance planning²⁶. Taken together, despite the absence of a non-IONM control group, our study highlights the clinical relevance of I-IONM as a tool that enhances intraoperative situational awareness, guides staged decision-making, and supports mechanism-based prognostic stratification when integrated with systematic postoperative laryngoscopic follow-up.

This study has several limitations that should be acknowledged. First, its retrospective design and single-center setting may limit external generalizability, although the high-volume nature of the institution and the standardized surgical and neuromonitoring protocols mitigate this concern to some extent. Second, the absence of a non-intraoperative nerve monitoring control group precludes direct assessment of the preventive efficacy of I-IONM. However, the primary objective of the study was not to evaluate injury prevention, but rather to characterize injury mechanisms and associated prognostic patterns following verified

LOS. Third, classification of RLN injury etiology was based on intraoperative assessment at the time of signal deterioration and may be subject to observer interpretation, particularly in cases involving overlapping mechanical mechanisms such as combined traction and compression. Finally, although a six-month follow-up period is widely accepted to distinguish transient from P-VCP, longer-term follow-up might reveal delayed functional recovery in a small subset of patients.

In conclusion, although I-IONM does not reliably prevent RLN injury, it provides real-time functional information that guides intraoperative decision-making and postoperative risk assessment. In this cohort with systematic postoperative laryngoscopic verification, a clear mechanism-dependent gradient in vocal cord recovery was observed, with traction and compression related injuries predominantly resulting in T-VCP, whereas transection was strongly associated with permanent dysfunction. Importantly, nearly half of intraoperative LOS events led to staged thyroidectomy, underscoring the role of I-IONM in mitigating the risk of bilateral VCP through informed surgical strategy modification. These findings support a contemporary interpretation of I-IONM as a tool for enhancing situational awareness and mechanism-based prognostic stratification, rather than as a guaranteed preventive technology in thyroid surgery.

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