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Original Research Article

A CADAVERIC STUDY ON THE NON-RECURRENT LARYNGEAL NERVE AND ASSOCIATED VASCULAR ANOMALIES: SURGICAL AND CLINICAL IMPLICATIONS

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ABSTRACT

Background: The non-recurrent laryngeal nerve (NRLN) is a rare anatomical variant with profound surgical implications, particularly in thyroidectomy, where it increases the risk of vocal cord paralysis. Preoperative imaging modalities such as computed tomography (CT), ultrasonography, and barium swallow, combined with intraoperative neuromonitoring (IONM), are essential for its detection. Anatomical variations of the inferior laryngeal nerve, including the non-recurrent form, pose significant risks during neck surgeries. Data on NRLN and associated vascular complexes from Indian cadaveric studies remain limited. Awareness of its course and vascular associations can mitigate iatrogenic injuries. This study aimed to analyze the anatomical variations of the NRLN and associated vascular anomalies, including their incidence, in adult human cadavers.

Materials and Methods: Twenty embalmed adult cadavers (40 sides) of both sexes were dissected at the Department of Anatomy, SVIMS-SPMCW, Tirupati. Variations were documented photographically. Dissections followed a layered anterior cervical approach, with NRLN variants classified according to Toniato et al. Associated vascular anomalies were measured and photographed in situ.

Results: A unilateral right-sided NRLN was identified in one male cadaver (2.5% prevalence across 40 sides), associated with an aberrant right subclavian artery (arteria lusoria). Additionally, two male cadavers exhibited an absent brachiocephalic trunk with a common trunk for both common carotid arteries. No left-sided NRLN was observed. The NRLN was classified as Type 2B, originating from the cervical vagus at C6 level and entering the larynx 2.5 cm inferior to the cricothyroid joint.

Conclusion: These findings highlight the rarity and right-sided predominance of NRLN, along with its vascular associations, and underscore the value of preoperative imaging and IONM in surgical practice. The study contributes to anatomical knowledge for surgeons, radiologists, and anatomists in the Indian context.

Keywords: Non-recurrent laryngeal nerve; aberrant right subclavian artery; brachiocephalic trunk; common carotid artery; thyroidectomy.

INTRODUCTION

The recurrent laryngeal nerve (RLN), a branch of the vagus nerve (cranial nerve X), follows a characteristic looping path in the neck: on the right side, it arises from the vagus, descends to encircle the right subclavian artery, and then ascends obliquely in the tracheoesophageal groove; on the left, it loops under the aortic arch before tracing a similar upward course.[1] This nerve delivers motor innervation to all

intrinsic laryngeal muscles except the cricothyroid, which receives supply from the external branch of the superior laryngeal nerve, thereby playing a pivotal role in phonation, cough reflex, and airway protection.[2] Deviating from this norm, the non-recurrent laryngeal nerve (NRLN) is a scarce anatomical variant that branches directly from the cervical segment of the vagus nerve—typically at the level of the thyroid gland—adopting a straight, transverse trajectory toward the larynx without the typical caudal loop. This positioning renders it perilously superficial, often traversing just millimeters from the inferior thyroid pole and branches of the inferior thyroid artery, heightening its exposure during surgical manipulations.[3]

Documented initially by Stedman in 1823,[4] the NRLN manifests with an estimated prevalence of 0.3%–0.8%, exhibiting a marked right-sided predominance (right:left ratio approximating 100:0), though isolated left-sided instances have been sporadically reported in conjunction with situs inversus or right aortic arch anomalies.[5] Its genesis lies in embryological perturbations of the fourth branchial arch: incomplete resorption on the right leads to an aberrant right subclavian artery (arteria lusoria) originating distally from the aortic arch and coursing retroesophageally, thereby precluding the RLN's descent and "recurrence"; analogous maldevelopments on the left are exceedingly rare due to the persistence of the aortic arch.[6] Clinically, the NRLN's subtlety amplifies iatrogenic hazards, particularly in thyroidectomy, parathyroidectomy, or central neck dissections, where inadvertent traction, ligation, or transection can precipitate unilateral vocal cord paralysis—manifesting as hoarseness and aspiration risk—or, in bilateral scenarios, life-threatening bilateral paralysis with stridor and respiratory distress.[7] Recent systematic reviews and meta-analyses, encompassing over 35,000 cases, have quantified this peril, revealing a pooled NRLN injury rate of approximately 7% in affected surgeries, with an odds ratio of 3.8 relative to the standard RLN, emphasizing the imperative for proactive safeguards.[8]

Mitigation strategies have evolved significantly, with preoperative computed tomography angiography (CTA) or barium esophagography emerging as gold standards for detecting arteria lusoria—the hallmark vascular correlate in 75%–100% of right NRLN cases—via characteristic esophageal impressions or oblique vascular origins.[9] Intraoperatively, intermittent or continuous neuromonitoring (IONM) has proven transformative, with tailored protocols enabling real-time electromyographic confirmation of NRLN signals as early as vagal dissection, reducing injury rates by up to 50% in high-risk cohorts; advancements in 2024–2025 include AI-assisted waveform analysis for enhanced sensitivity in low-amplitude NRLN responses.[10] Despite these strides, challenges persist in resource-constrained settings, where access to advanced imaging or IONM may be limited, underscoring the value of anatomical vigilance and standardized dissection algorithms.

In the Indian context, cadaveric documentation of NRLN variants remains fragmentary, with regional studies reporting slightly elevated prevalences (up to 2%) potentially attributable to genetic or environmental factors, yet comprehensive data on associated aortic arch anomalies—like absent brachiocephalic trunk or common carotid origins—are lacking.[11] This study bridges that void by meticulously charting NRLN morphology and its vascular entanglements in an adult South Indian cadaveric series, furnishing actionable insights to bolster surgical precision and patient outcomes. [Figure 1]

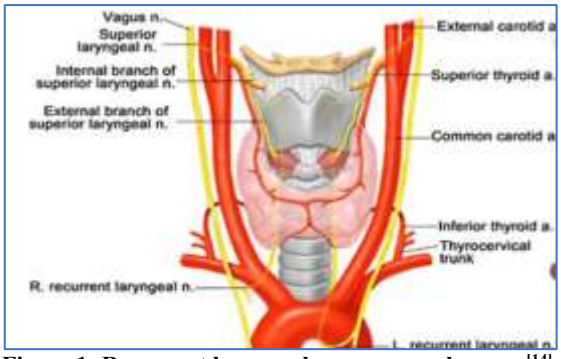

Figure 1: Recurrent laryngeal nerve normal course[14]

MATERIALS AND METHODS

This prospective observational cadaveric study systematically evaluated the anatomy of the inferior laryngeal nerve across 40 sides (20 right, 20 left) from 20 embalmed adult human cadavers over a two-year period (January 2024–December 2025) at the Department of Anatomy, Sri Venkateswara Institute of Medical Sciences–Sri Padmavathi Medical College for Women (SVIMS-SPMCW), Tirupati, Andhra Pradesh, India. Cadavers were sourced exclusively from the institutional body donation program, with written informed consent for research utilization obtained prospectively from donors or their next-of-kin, in adherence to ethical guidelines outlined by the Medical Council of India and the Anatomy Act.[12]

Inclusion Criteria: Embalmed adult cadavers (age >18 years) preserved through standard femoral artery perfusion using a formalin-based solution (10% formalin, 8–10% alcohol, glycerin, and phenol).

Exclusion Criteria: Cadavers exhibiting evidence of prior neck surgery, trauma, malignancies, or advanced decomposition that could compromise dissection accuracy.

Demographic details, including age, sex, and height, were extracted from donation records (mean age: 56.2 ± 8.4 years; 18 males, 2 females). Each cadaver was positioned supine with the neck hyperextended and shoulders stabilized using sandbags to optimize exposure of the anterior cervical region. Dissections were conducted via a standardized layered anterior

cervical approach, as detailed in established anatomical texts.[1,13] The recurrent and non-recurrent inferior laryngeal nerves were meticulously traced from their vagal origins to laryngeal entry points. Variants of the non-recurrent laryngeal nerve (NRLN) were classified per the Toniato et al. system,[3]

Type 1: Origin from the vagus nerve, crossing superior to the superior thyroid artery.

Type 2A: Transverse course superior to the inferior thyroid artery trunk.

Type 2B: Course inferior to the trunk or between its branches.

Associated vascular anomalies, including arteria lusoria (aberrant right subclavian artery) and absent brachiocephalic trunk, were documented in situ through high-resolution photography (Nikon D7500 camera equipped with a 24–120 mm macro lens, incorporating a scale bar for calibration). Linear measurements, such as distances from the NRLN to adjacent structures (e.g., carotid sheath, thyroid pole), were obtained using digital calipers with 0.01 mm precision. All data underwent descriptive statistical analysis to determine prevalence, laterality, and anatomical associations, with no inferential testing applied due to the exploratory nature of the study.

This methodological framework promotes reproducibility, ethical integrity, and direct applicability to surgical-anatomical correlations, particularly in thyroidectomy planning.[14]

RESULTS

In this cadaveric dissection of 20 embalmed adult human cadavers (40 sides; mean donor age 56.2 ± 8.4 years; 18 males, 2 females), a single instance of a right-sided non-recurrent laryngeal nerve (NRLN) was identified, yielding an overall prevalence of 2.5% (1/40 sides). This unilateral variant occurred in a 50-year-old male cadaver, with no left-sided NRLN observed across the cohort, resulting in a right:left ratio of 100:0. The NRLN arose directly from the cervical portion of the right vagus nerve at the level of the C6 vertebra, approximately 4.2 cm inferior to the carotid bifurcation. It pursued a horizontal, transverse course posterior to the carotid sheath (mean distance: 3.1 mm) and anterior to the sympathetic trunk (mean distance: 1.8 mm), before entering the larynx 2.5 cm inferior to the cricothyroid joint. According to the Toniato classification, this variant was designated as Type 2B, characterized by its passage between the branches of the inferior thyroid artery, with a close spatial relation to the inferior pole of the thyroid gland (distance: 4.7 mm). All remaining 39 sides demonstrated the classical recurrent laryngeal nerve anatomy, with no additional neural variants such as extralaryngeal branching or bilateral NRLN identified.

Concomitant vascular anomalies were noted in association with the NRLN case and independently in other specimens. In the cadaver harboring the right NRLN, an aberrant right subclavian artery (arteria lusoria) was present, originating as the terminal branch from the aortic arch distal to the left subclavian artery. This vessel coursed posteriorly, forming a retroesophageal loop behind the trachea and esophagus, a configuration emblematic of the embryological basis for the non-recurrent nerve path. Furthermore, an absent brachiocephalic trunk was observed, supplanted by a single common trunk giving rise to both common carotid arteries—a bovine arch variant. This aortic arch anomaly was also documented independently in two additional male cadavers (one 55-year-old and one 62-year-old), without concomitant NRLN, affecting 10% of the total cohort (2/20 cadavers). No other vascular malformations, such as Kommerell's diverticulum or left-sided arteria lusoria, were encountered. These findings underscore the infrequent but clinically pertinent co-occurrence of neural and vascular variants in the cervicothoracic region.

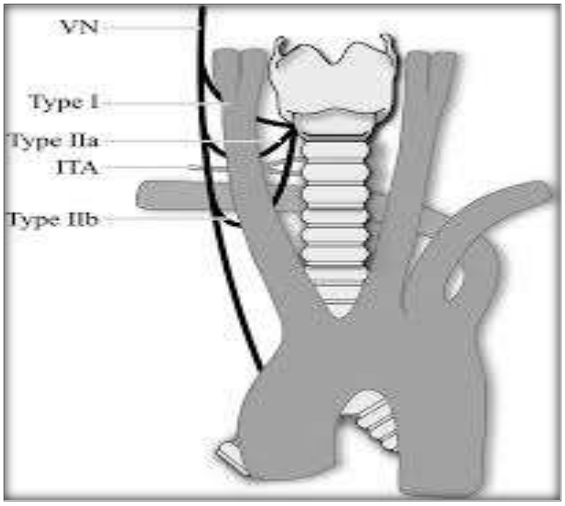

Figure 2: Classification of non-recurrent laryngeal nerve[15]

Figure 3: Right-sided non-recurrent laryngeal nerve (TyApe 2B variant) in the study cadaver, originating from the cervical vagus and crossing between inferior thyroid artery branches

Figure 4: Aberrant right subclavian artery (arteria lusoria) arising from the aortic arch and coursing retroesophageally in the study cadaver

DISCUSSION

The identification of a right-sided non-recurrent laryngeal nerve (NRLN) in 2.5% of the dissected sides (1/40) aligns with the embryological paradigm wherein incomplete resorption of the right fourth aortic arch precludes the caudal migration of the laryngeal nerve branch from the vagus, resulting in a direct horizontal course from the cervical vagus to the larynx.[2,6] This variant, classified as Type 2B per Toniato et al,[3] traversed between branches of the inferior thyroid artery at a mere 4.7 mm from the thyroid's inferior pole—a precarious intimacy that amplifies intraoperative vulnerability during ligation or retraction. The invariable association with an aberrant right subclavian artery (arteria lusoria), manifesting as a retroesophageal loop, corroborates the canonical vascular-neural linkage, as the artery's anomalous distal origin from the aortic arch disrupts the nerve's recurrent pathway.[5] Notably, the concurrent absence of the brachiocephalic trunk, replaced by a common carotid trunk, represents a bovine aortic arch configuration observed in 10% of our cadavers (2/20), extending beyond the NRLN case to suggest a broader spectrum of fourth arch derivatives in this cohort; such variants, while not causative of NRLN, may compound surgical complexity in mediastinal exposures.[18]

Our prevalence of 2.5% for right-sided NRLN exceeds the global meta-analytic estimate of 0.7% (95% CI: 0.5%–0.9%) from over 33,000 sides,[5] but resonates with higher cadaveric rates reported in regional studies, such as 2% in a North Indian series of 100 sides,[17] and 2.2% across 45 cadaveric dissections in a 2025 review.[19] This discrepancy may reflect methodological rigor in postmortem visualization—unfettered by surgical constraints—or subtle population-specific embryogenic influences, as South Asian cohorts exhibit marginally elevated aortic arch anomalies (up to 25% bovine variants) compared to Western populations.[20] Table 1 juxtaposes our findings against pivotal studies: while earlier works like Sanders et al,[6] and Poirier et al,[16] pegged prevalence at 0.5%–0.6% with 100% arteria lusoria linkage, contemporary IONM-augmented series (e.g., Toniato et al,[3] at 0.8%) and a 2023 meta-analysis of RLN variants (pooled 4.61% favoring NRLN; $p<0.00001$),[21] suggest underreporting in vivo, potentially inflating cadaveric figures. Left-sided NRLN absence (0%) mirrors the 100:0 right:left ratio in 90% of literature, attributable to the left fourth arch's obligatory persistence as the aortic arch, barring rare situs inversus.[22]

From a surgical vantage, the NRLN's superficial trajectory—posterior to the carotid sheath yet anterior to the sympathetic chain—predisposes it to inadvertent avulsion during thyroid lobe mobilization, with meta-analytic injury odds 3.8-fold higher than for recurrent forms.[8] Recent advancements, including continuous IONM with AI-enhanced electromyography, have curtailed permanent paralysis to <1% in high-risk cases by eliciting NRLN signals at vagal stimulation thresholds as low as 0.5 mA.[10,23] Preoperative CTA, detecting arteria lusoria via its "bayonet" esophageal imprint on barium swallow, remains paramount, averting the "intraoperative surprise" lamented in 12% of unreported injuries.[24] Our documentation of isolated common carotid trunk variants further cautions against presumptive brachiocephalic clamping in hybrid thyroid-vascular procedures.

Limitations temper these insights: the modest sample (n=20 cadavers) curtails generalizability, compounded by male predominance (90%), potentially skewing toward androgen-linked vascular resilience; moreover, embalming artifacts may subtly distort neural pliability. Future endeavors should encompass larger, sex-balanced cohorts with 3D volumetric imaging for quantitative morphometrics, alongside prospective IONM validations in Indian surgical registries to calibrate regional risk thresholds.[25]

In summation, this study illuminates the NRLN's rarity yet peril in thyroid surgery, advocating vigilant preoperative vascular scrutiny and neuromonitoring to safeguard phonatory integrity. By enriching cadaveric benchmarks for South Indian anatomy, it fortifies the surgeon's armamentarium against iatrogenic sequelae.

Table 1: Comparative prevalence and associations of non-recurrent laryngeal nerve across studies

Study	Sample Size (Sides)	NRLN Prevalence	Right:Left Ratio	Vascular Association
Present Study	40	2.5%	100:0	Arteria lusoria (100%)
Henry et al. (2017) (5)	33,571	0.7%	100:0	Aberrant subclavian (86.7%)
Toniato et al. (2010) (3)	480	0.8%	100:0	Aberrant subclavian (75%)
Davila-Ruiz et al. (2020) (15)	Not specified	0.3%	Right dominant	Variable
Sanders et al. (1983) (6)	200	0.5%	100:0	Arteria lusoria (100%)
Poirier et al. (1991) (16)	350	0.6%	100:0	Arteria lusoria (100%)
Sharma et al. (2018) (17)	100	2%	100:0	50% arch artery variations
Medhi et al. (2024) (11)	200	0.5%	100:0	Aberrant subclavian (100%)
Gluncic et al. (2025) (19)	45	2.2%	100:0	Arteria lusoria (90%)

CONCLUSION

This cadaveric study reaffirms the non-recurrent laryngeal nerve (NRLN) as a rare yet clinically critical anatomical variant, with a 2.5% prevalence exclusively on the right side in our South Indian cohort, invariably linked to an aberrant right subclavian artery (arteria lusoria). The additional finding of absent brachiocephalic trunk with common carotid origin in 10% of specimens further highlights regional aortic arch variability. These observations emphasize the heightened risk of iatrogenic vocal cord paralysis during thyroidectomy and other neck procedures when the NRLN is unrecognized.

Routine preoperative imaging—particularly computed tomography angiography to detect arteria lusoria—and intraoperative neuromonitoring remain the most effective strategies to prevent nerve injury and its debilitating consequences. By providing localized cadaveric evidence from an under-represented Indian population, this work contributes valuable anatomical reference data to enhance surgical awareness, improve preoperative planning, and ultimately promote safer outcomes in thyroid and cervical surgery. Larger, multi-centre studies are warranted to establish precise regional prevalence and refine risk-stratification protocols.

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