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Short, thick neck phenotype as an anatomical determinant of thyroidectomy complexity: A prospective single-center observational study

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A R T I C L E I N F O

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Neck phenotype
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A B S T R A C T

Background: Neck configuration is a key determinant of thyroidectomy difficulty, yet it lacks a simple, reproducible definition for research, risk stratification, and operative planning. A short, thick neck is intuitively associated with limited exposure and longer operative times, but evidence has been largely anecdotal.

Methods: In a prospective single-center observational cohort, 843 consecutive adults undergoing primary total thyroidectomy (2019–2024) had preoperative neck phenotype assessed by anesthetists using neck circumference (NC) and cervicomental height (CMH). A Difficult Neck Phenotype Index (DNPI = NC/CMH) was derived. Associations with operative time, exposure maneuvers, Thyroidectomy Difficulty Scale (TDS), and postoperative complications were examined using multivariable models adjusting for BMI, thyroid volume, Graves' disease, malignancy, and retrosternal extension.

Results: Mean NC, CMH, and DNPI were 372 ± 41 mm, 200 ± 27 mm, and 3.88 ± 0.67, respectively. Higher DNPI correlated with longer operative time (Spearman $\rho = 0.41$, $p < 0.001$) and increased use of exposure maneuvers (partial strap division, long retractors, lateral incision extension), as well as greater blood loss and drain placement, independent of clinical confounders. An exploratory DNPI cut-off of 4.1 was associated with operative time > 75th percentile with an AUC of 0.78 (95% CI 0.71–0.84), sensitivity 76.3%, and specificity 68.5%. Postoperative morbidity was low, and DNPI was not an independent predictor of RLN injury, hypocalcemia, cervical hematoma, or wound complications.

Conclusions: DNPI is an exploratory, internally derived morphometric marker that operationalizes neck phenotype and was independently associated with intraoperative complexity in total thyroidectomy. In a high-volume specialist setting, difficult neck phenotype was associated with greater technical demand and resource use without a detectable increase in short-term morbidity, although power for rare events was limited. External validation across populations, techniques, and institutional volumes is warranted.

1. Introduction

Patient-specific anatomical factors are increasingly recognized as key determinants of safety, technical complexity, and clinical outcomes in cervical endocrine surgery, yet they remain incompletely characterized and inconsistently reported in the thyroidectomy literature [1–4]. Among these, the "difficult neck" is intuitively recognized in daily practice but lacks a clear, reproducible, and clinically oriented definition suitable for research, risk stratification, and operative planning [5–7]. In particular, the short, thick neck configuration—characterized by reduced cervical length, increased soft-tissue bulk, robust muscular habitus, large neck circumference, and restricted extension—is widely

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perceived to impair exposure and increase technical demands, although this perception is supported mainly by anecdotal rather than morphometric evidence.

From a surgical standpoint, this phenotype may require more extensive dissection, enhanced retraction, and greater cranial traction on the laryngotracheal complex, leading to prolonged operative time, increased blood loss, and more challenging identification and preservation of critical structures, including the recurrent laryngeal nerves (RLN), external branch of the superior laryngeal nerve (EBSLN), and parathyroid glands, with a potential impact on complication rates. Several scoring systems and predictive tools, including the Thyroidectomy Difficulty Scale (TDS) and preoperative composite models, have been proposed to quantify surgical difficulty, but they largely omit standardized measures of neck configuration and do not specifically capture the challenge posed by a short, thick neck [2,8–11].

Parallel work in airway assessment has highlighted the relevance of neck circumference and related anthropometric ratios, yet these parameters have not been systematically translated into a simple, preoperative metric tailored to cervical endocrine surgery [12–14]. Consequently, the impact of neck phenotype on perioperative risk and operative complexity remains underappreciated and is seldom integrated into counseling, case selection, operating room planning, benchmarking, and trial design, particularly in studies evaluating novel or minimally invasive approaches [15].

The objective of the present study is to propose and prospectively evaluate an operative definition of the difficult neck in cervical endocrine surgery, focusing on the short, thick neck phenotype and its association with objective indicators of complexity and risk. Neck configuration was quantified using two simple preoperative morphometric measurements—neck circumference and cervicomental height—obtained by the anesthetist with the surgeon blinded to the raw values, and combined into a Difficult Neck Phenotype Index (DNPI). The study aims to correlate DNPI and its individual components with operative time, need for enhanced retraction or partial strap division, validated intraoperative difficulty scores, and perioperative complications after total thyroidectomy. By.

2. Methods

2.1. Study design and population

This prospective single-center observational cohort study included consecutive adults (≥18 years) undergoing primary total thyroidectomy between January 2019 and December 2024 at a high-volume endocrine surgery center. The primary endpoint was the association between preoperative neck phenotype and intraoperative complexity, defined a priori by operative time and need for extended exposure maneuvers. Postoperative complications were prespecified as secondary outcomes.

Exclusion criteria were hemithyroidectomy; concurrent central or lateral lymph node dissection; reoperative or combined thyroid–parathyroid surgery; endoscopic or robotic approaches; prior major cervical procedures; limited cervical extension; pregnancy; pre-existing vocal fold paralysis; coagulation disorders; and incomplete data sets.

To minimize heterogeneity in baseline procedure type and isolate the impact of neck phenotype on a relatively homogeneous operation, we restricted the cohort to primary total thyroidectomy and excluded reoperative thyroid surgery, concomitant central or lateral lymph node dissection, and endoscopic or robotic approaches.

2.2. Surgical and perioperative management

All procedures were performed by an experienced endocrine surgeon following standardized institutional protocols and international guidelines, with routine use of intraoperative neuromonitoring and autofluorescence when available [16,17].

2.3. Ethics

The study was approved by the local Institutional Review Board (Protocol No. 2.792.420) and conducted in accordance with the Declaration of Helsinki [18]. All patients provided written informed consent. Reporting followed the STROBE guidelines [19].

2.4. Preoperative variables and innate thyroid characteristics

Demographic data, BMI, ASA class, smoking status were prospectively recorded [20,21]. Baseline biochemical parameters, including thyroid function tests, calcium, and parathyroid hormone levels, were collected according to institutional standards. In addition to neck morphometrics and general clinical variables, we prospectively collected several gland-related characteristics known to influence thyroidectomy complexity. These included preoperative thyroid volume, presence of retrosternal extension according to established radiologic definitions, underlying diagnosis (multinodular goiter, Graves disease, differentiated thyroid carcinoma, or other benign nodular disease), and chronic thyroiditis when reported by preoperative imaging and/or final histology [22–24]. Thyroid volume was estimated by ultrasound using the ellipsoid formula [25]. These variables were prespecified covariates and were incorporated into univariable analyses and multivariable regression models assessing the independent association between DNPI and operative complexity endpoints.

2.5. Neck phenotype assessment and DNPI

Neck phenotype was assessed preoperatively by trained anesthetists during routine pre-anesthetic evaluation, with surgeons blinded to measurements. Assessments were performed in the upright position using a non-elastic measuring tape [26–28].

In our study, neck circumference and cervicomental height were measured by a small, dedicated group of 3 anesthetists who were trained on a written standardized protocol during routine pre-anesthetic evaluation, following that protocol (upright position, non-elastic tape, neck circumference at the level of the cricothyroid membrane, cervicomental height from the menton to the superior manubrial border), while surgeons were blinded to the raw values. This approach was chosen to approximate real-world practice and reduce potential measurement bias, a single measurement of each parameter was recorded per patient; duplicate measurements were not routinely obtained, and no formal intra- or inter-observer reproducibility testing was performed. The reproducibility of DNPI therefore remains to be formally established.

Neck circumference (NC) was measured at the level of the cricothyroid membrane, and cervicomental height (CMH) as the distance between the menton and the superior border of the manubrium. Both parameters were analyzed as continuous variables and stratified into sex-specific tertiles.

The Difficult Neck Phenotype Index (DNPI) was calculated as NC/CMH. Higher values reflected a proportionally shorter and thicker neck configuration. A ratio was selected in preference to NC or CMH alone because it expresses cervical width relative to cervical length and is intended to capture the depth-to-length geometry that governs surgical exposure independently of absolute body size; whether the ratio added information beyond its individual components and BMI was tested explicitly in the analyses below. A DNPI–BMI ratio was explored to account for overall body habitus [23].

All measurements were obtained in the upright position during routine pre-anesthetic evaluation, which reflects typical preoperative workflows but does not capture dynamic changes in cervical geometry that occur after transition to the supine, extended operative position.

2.6. Intraoperative variables and assessment of complexity

identification of RLN and EBSLN, parathyroid autotransplantation, and intraoperative adverse events. Several of these variables (incision extension, partial strap muscle division, use of long retractors, and drain placement) reflect intraoperative decisions that are partly operator- and institution-dependent and are therefore not purely objective anatomical endpoints.

Surgical difficulty was assessed using the Thyroidectomy Difficulty Scale (TDS), a validated intraoperative score that grades difficulty largely on gland- and disease-related factors (e.g. gland size, vascularity, adhesions, and thyroiditis). The TDS was assigned by the operating surgeon at the end of each procedure [8]. Because the surgeon was blinded only to the numerical neck measurements and not to the patient's appearance, TDS scoring was not formally blinded to neck phenotype or to the study hypotheses.

2.7. Postoperative outcomes and follow-up

Postoperative outcomes were assessed during hospitalization and scheduled follow-up. Primary endpoints included cervical hematoma requiring reoperation, RLN injury confirmed by laryngoscopy, and hypocalcemia/hypoparathyroidism defined by biochemical and clinical criteria [32,33]. Recurrent laryngeal nerve palsy and hypoparathyroidism were classified as permanent only when they persisted beyond 6 months after surgery; because mean follow-up was short (7.0 $\pm$ 3.1 months) and not all patients had completed 6 months of observation at analysis, permanent-outcome rates should be regarded as minimum estimates. Wound complications, drain use, and length of stay were also recorded. All patients underwent routine pre- and postoperative laryngoscopy.

2.8. Statistical analysis and power analysis

Data were analyzed using R (version 4.3.2). Continuous variables are presented as mean $\pm$ SD or median (IQR), and categorical variables as counts and percentages. Group comparisons used Student's *t*-test, Mann–Whitney *U* test, Chi-square, or Fisher's exact test, as appropriate.

Correlations were evaluated using Spearman's coefficient. Logistic regression models were used to identify independent predictors of operative complexity and postoperative complications. Candidate covariates for the multivariable models were variables with $p < 0.10$ at univariable analysis together with a pre-specified fixed set. For the intraoperative-complexity models (prolonged operative time, drain use, use of long retractors, incision extension, and greater blood loss), the covariates entered were DNPI, age, BMI, thyroid volume, Graves' disease, malignancy, and retrosternal extension. DNPI, age, and BMI were forced into every model: DNPI as the exposure of interest, and age and BMI as pre-specified demographic and habitus confounders plausibly related to both neck geometry and operative difficulty, irrespective of their univariable p-value. Because DNPI is derived mathematically from NC and CMH and is related to BMI, the component measurements (NC and CMH) were never entered in the same model as DNPI and were analyzed only in separate models. Collinearity among covariates was assessed using variance inflation factors, with no variable exceeding conventional thresholds.

Receiver operating characteristic (ROC) analyses assessed the ability of DNPI to identify prolonged operative time, defined a priori as an operative time above the cohort 75th percentile (90 min) as a pragmatic marker of the most time-consuming procedures. A candidate cut-off was derived using the Youden index. Because this cut-off was derived and tested in the same dataset, no internal resampling (e.g. bootstrapping) or external validation was performed; the resulting value is therefore reported as exploratory and hypothesis-generating rather than as an established clinical decision threshold. "Greater blood loss" was modelled as a dichotomous outcome defined as estimated blood loss above the cohort 75th percentile. Missing data affected fewer than 2% of observations, were confined to a small number of covariates (smoking status, ASA class, and ultrasound-estimated thyroid volume), and were handled by complete-case analysis; the number of observations available for each model is reported in the corresponding table footnote. Statistical significance was set at $p < 0.05$ (Table 1).

No formal a priori sample size calculation was performed; instead, we included all consecutive eligible patients over the 6-year study period, yielding a cohort of 843 primary total thyroidectomies. Post hoc assessments indicated that this sample provided adequate power to detect clinically relevant associations between DNPI (as a continuous and categorical variable) and primary complexity endpoints such as operative time and extended exposure maneuvers. However, given the relatively low incidence of major complications and the subdivision of patients into three DNPI tertiles, the study was underpowered to reliably detect modest differences in rare adverse events between neck phenotype strata, particularly when simultaneously adjusting for gland-related factors such as pathology, retrosternal extension, and thyroid volume.

3. Results

3.1. Overall cohort profile

A total of 843 consecutive patients undergoing total thyroidectomy were included (Supplementary Fig. 1). Mean age was 51.2 $\pm$ 13.8 years, 67% (n = 565) were female, and median BMI was 26.4 kg/m^2 (IQR 23.8–29.1). Most patients were Caucasian (89%), and 7% were active smokers. Main indications were multinodular or nodular goiter (49%, n = 413), Graves' disease (14%, n = 118), and differentiated thyroid carcinoma (37%, n = 312). Retrosternal extension was present in 9% (n = 76), and 47% (n = 396) reported compressive symptoms. No patient underwent prophylactic or therapeutic neck dissection. Mean follow-up was 7.0 $\pm$ 3.1 months (Supplementary Table 1).

3.2. Intraoperative findings and postoperative outcomes

Operative time averaged 77 $\pm$ 19 min (median 78 min, IQR 66–90; 75th percentile 90 min). Median skin incision length was 45 mm (IQR 40–50). Strap muscle division was required in 6.0% and lateral incision extension in 2.4%; no sternotomies were performed. Continuous neuromonitoring was used in 43.0%, with failure in 3.2%. All four parathyroid glands were identified in 71.0%, and autotransplantation was performed in 6.0%. Mean blood loss was 23 $\pm$ 8 mL (median 20 mL, IQR 15–30).

Recurrent laryngeal nerve outcomes were analyzed per nerve at risk (1686 nerves in 843 patients), whereas all other analyses were patient-based; transient and permanent RLN palsy occurred in 9.0% and 0.8% of nerves, respectively, and the EBSLN was identified in 79.0%. Eleven patients (1.3%) underwent staged completion thyroidectomy. Transient hypocalcemia occurred in 23.0% and permanent hypocalcemia in 2.4%. Cervical hematoma requiring reoperation occurred in 1.0%, and seroma in 1.5%. Mean hospital stay was 2.2 $\pm$ 1.2 days (Supplementary Table 2).

3.3. Neck morphometrics and phenotype

Neck measurements were available for all patients. Mean NC was 372 $\pm$ 41 mm, mean CMH 200 $\pm$ 27 mm, and mean DNPI 3.88 $\pm$ 0.67. Sex-specific DNPI tertiles identified progressively thicker and shorter neck configurations, with the highest tertile corresponding to a short, thick phenotype (Fig. 2). These tertile boundaries are descriptive summaries of the cohort distribution and are distinct from the exploratory, ROC-derived cut-off of 4.1 reported below; the two should not be used interchangeably.

Higher NC, lower CMH, and higher DNPI were associated with obesity ($p < 0.001$), male sex ($p = 0.002$ for NC; $p = 0.008$ for DNPI), and difficult intubation ($p = 0.014$). DNPI increased with BMI, consistent with its association with obesity, but was not reducible to BMI: in

Table 1

Neck morphometric measurements and univariable clinical associations in 843 consecutive patients undergoing total thyroidectomy (January 2019–December 2024). Neck circumference (NC), cervicomental height (CMH), and Difficult Neck Phenotype Index (DNPI) were measured preoperatively using standardized anatomical landmarks. Primary outcome variables presented as mean ± standard deviation and range. Univariable analysis examined associations between morphometric indices and demographic, clinical, and pathological variables; $p < 0.05$ denotes statistical significance. Patients stratified into tertiles by DNPI to characterize phenotypic "short, thick" (highest tertile, DNPI > 4.5) versus "slender, elongated" (lowest tertile, DNPI < 3.2) cervical morphology. These tertile boundaries are descriptive, cohort-based cut-points and are distinct from the exploratory ROC-derived cut-off (DNPI 4.1) reported in the main text and Table 3. Arrow notation: ↑ = significantly increased; ↓ = significantly decreased.

1a. Primary morphometric measurements

Measurement	Mean ± SD	Range	Clinical significance
Neck Circumference (NC, mm)	372 ± 41	290–490	Marker of neck adiposity and obesity-related phenotype; associated with difficult intubation
Cervicomental Height (CMH, mm)	200 ± 27	98–290	Inversely related to obesity; reduced height indicates vertical compression
Difficult Neck Phenotype Index (DNPI)	3.88 ± 0.67	2.3–5.6	Quantifies "short, thick" (high DNPI) vs. "slender, elongated" (low DNPI) phenotype

1b. Phenotypic classification by DNPI tertiles

DNPI tertile	N (%)	Phenotype	Characteristics	Expected morphometry
Lowest (<3.2)	281 (33.3%)	Slender, elongated	Adequate vertical height, minimal adiposity, excellent surgical access	NC: 310–352 mm; CMH: 227–240 mm
Middle (3.2–4.5)	281 (33.3%)	Intermediate	Balanced proportions, standard neck dimensions	NC: 360–384 mm; CMH: 192–208 mm
Highest (>4.5)	281 (33.3%)	Short, thick	Limited vertical height, increased adiposity, challenging surgical access	NC: 392–434 mm; CMH: 160–186 mm

1c. Univariable analysis: associations with morphometric indices

Variable	N or subgroup (%)	NC association	CMH association	DNPI association	p-value
Significant associations ($p < 0.05$)					
Obesity (BMI > 30 kg/m^2)	269 (31.9%)	↑ Increased	↓ Decreased	↑ Increased	**<0.001**
Male sex	278 (33.0%)	↑ Increased	Borderline	↑ Increased	**0.002–0.008**
Difficult intubation (Cormack–Lehane III–IV)	67 (7.9%)	↑ Increased	↓ Decreased	↑ Increased	**0.014**
Non-significant associations ($p \geq 0.05$)					
Age (continuous, 18–85 years)	843 (100%)	No association	No association	No association	0.64
Ethnicity (Caucasian vs. Other)	750 / 93 (89% / 11%)	No association	No association	No association	0.58
Pathology type (benign vs. malignant)	531 / 312 (63% / 37%)	No association	No association	No association	0.41
Retrosternal goiter (yes vs. no)	76 / 767 (9.0% / 91.0%)	No association	No association	No association	0.27
Preoperative thyroid volume (mL)	Mean 18.5 ± 8.2	No association	No association	No association	0.49
Biochemical thyroid status	TSH, FT4 continuous	No association	No association	No association	0.70
Chronic thyroiditis (yes vs. no)	160 / 683 (19.0% / 81.0%)	No association	No association	No association	0.73

Abbreviations

- **NC:** Neck circumference
- **CMH:** Cervicomental height
- **DNPI:** Difficult Neck Phenotype Index
- **BMI:** Body mass index
- **TSH:** Thyroid-stimulating hormone (normal 0.4–4.0 mIU/L)
- **FT4:** Free thyroxine (normal 10.0–20.0 pmol/L)
- **TPO:** Thyroid peroxidase antibody (positive if >35 IU/mL)
- **TgAb:** Thyroglobulin antibody (positive if >40 IU/mL)
- **RLN:** Recurrent laryngeal nerve
- **CIONM:** Continuous intraoperative neuromonitoring
- **CT:** Computed tomography

multivariable models it retained an independent association with operative complexity after adjustment for BMI (see below). No significant associations were observed with age, ethnicity, pathology, retrosternal extension, thyroid volume, thyroid.

3.4. Innate thyroid characteristics

In the overall cohort, 49% of patients had multinodular or nodular goiter, 14% had Graves disease, and 37% had differentiated thyroid carcinoma, while retrosternal extension was present in 9% of cases. Median ultrasound-estimated thyroid volume and the prevalence of chronic thyroiditis did not differ significantly across DNPI tertiles, and DNPI showed no correlation with thyroid volume, underlying diagnosis, retrosternal extension, or chronic thyroiditis (all $p > 0.05$). In multivariable models, DNPI remained independently associated with operative time and exposure maneuvers after adjustment for thyroid volume, Graves disease, malignancy, and retrosternal extension, indicating that neck phenotype exerts an effect on operative complexity that is at least partly independent of intrinsic gland characteristics.

3.5. Impact of neck phenotype on intraoperative complexity

DNPI was significantly associated with intraoperative complexity. Operative time increased across DNPI tertiles (median 70 vs 78 vs 88 min, $p < 0.001$), with a positive correlation as a continuous variable ($\rho = 0.41$, $p < 0.001$). Patients in the highest tertile more frequently required strap muscle division (15.3% vs 4.7%, $p = 0.004$), long retractors (19.1% vs 2.4%, $p < 0.001$), and incision extension (9.5% vs 0.5%, $p = 0.008$). Blood loss was modestly higher (40 vs 17 mL, $p = 0.02$).

Length of stay did not differ across tertiles ($p = 0.47$). High-DNPI patients had longer incisions (65 vs 55 mm, $p = 0.01$) and more frequent drain use (15.6% vs 3.6%, $p = 0.003$). TDS scores were similar across groups, suggesting that DNPI may capture an anatomical dimension of complexity that is only partially reflected in disease-focused scores; because formal comparison of model performance between DNPI and TDS was not undertaken, this interpretation should be regarded as exploratory (Fig. 3).

3.6. DNPI–TDS relationship

TDS scores were overall low and did not differ significantly across DNPI tertiles, despite clear stepwise increases in operative time and the need for extended exposure maneuvers in patients with higher DNPI. In correlation analyses, DNPI showed only a weak, non-significant association with TDS, whereas it correlated moderately with operative time and process-related complexity endpoints. This pattern suggests that DNPI captures an anatomical dimension of difficulty – related to exposure and working angles – that is only partially reflected in the disease-focused domains of the TDS.

This divergence between stable TDS scores and progressively higher process-related complexity across DNPI tertiles suggests that DNPI and TDS are sampling distinct, only partially overlapping domains of surgical difficulty (Fig. 1).

3.7. Postoperative morbidity across neck phenotypes

DNPI tertiles were not associated with transient or permanent RLN palsy, hypocalcemia, cervical hematoma, or wound complications (all $p > 0.05$) (Table 2). Owing to low event rates, analyses of rare complications should be interpreted cautiously. Multivariable odds ratios were close to unity with wide confidence intervals.

Given the low incidence of major adverse events in this high-volume cohort, these neutral associations between DNPI and postoperative morbidity should be interpreted with caution, as the study is underpowered to detect small to moderate risk differences for rare complications.

3.8. Multivariable analysis and predictive performance

In adjusted models, DNPI remained independently associated with intraoperative complexity but not with postoperative complications. Each one-unit increase in DNPI increased the odds of prolonged operative time (OR 2.15, 95% CI 1.52–3.06, $p < 0.001$), drain use (OR 1.72, $p = 0.005$), long retractors (OR 1.89, $p = 0.001$), incision extension (OR 1.64, $p = 0.03$), and higher blood loss (OR 1.58, $p = 0.01$) (Table 3).

When analyzed separately, NC and CMH were associated with operative time, but DNPI provided superior model fit and discrimination. ROC analysis showed moderate discrimination for prolonged operative time (AUC 0.78, 95% CI 0.71–0.84). An exploratory DNPI cut-off of 4.1 yielded a sensitivity of 76.3% and specificity of 68.5%.

An exploratory DNPI cut-off of 4.1, derived using the Youden index within the same dataset, identified patients with higher odds of prolonged operative time and composite intraoperative complexity events. However, this threshold was not subjected to internal resampling or external validation and should therefore be considered hypothesis-generating rather than a definitive decision point. These values indicate moderate discriminative performance for a simple two-parameter anthropometric index and support the use of DNPI as a pragmatic preoperative marker of increased operative complexity, rather than as a stand-alone decision rule for individual patients.

4. Discussion

This prospective study offers a large-scale, morphometry-based characterization of the difficult neck in thyroid surgery, demonstrating

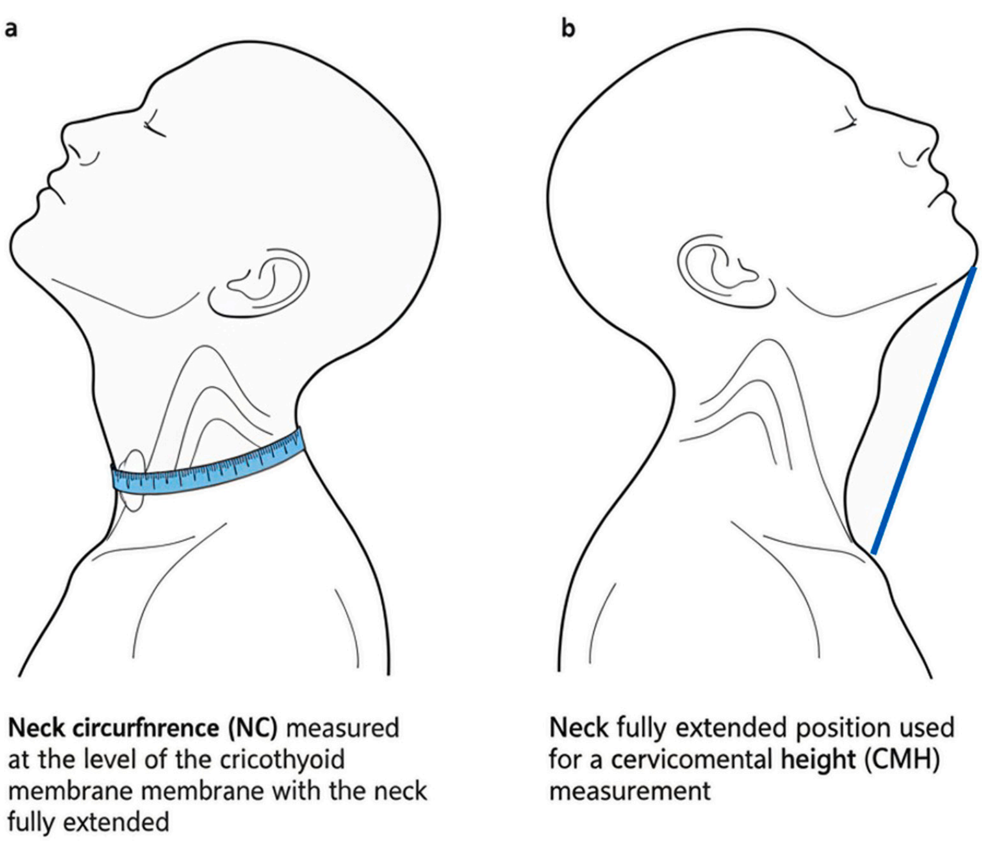

Fig. 1. Preoperative neck phenotype assessment. (a) Measurement of neck circumference (NC) using a flexible, non-elastic tape placed horizontally at the level of the cricothyroid membrane, just below the thyroid cartilage, with the patient seated upright and the head in a neutral position, consistent with the pre-anesthetic assessment described in the Methods. (b) Upright, neutral head position used for cervicomental height (CMH) assessment, defined as the linear distance from the menton to the superior border of the sternal manubrium.

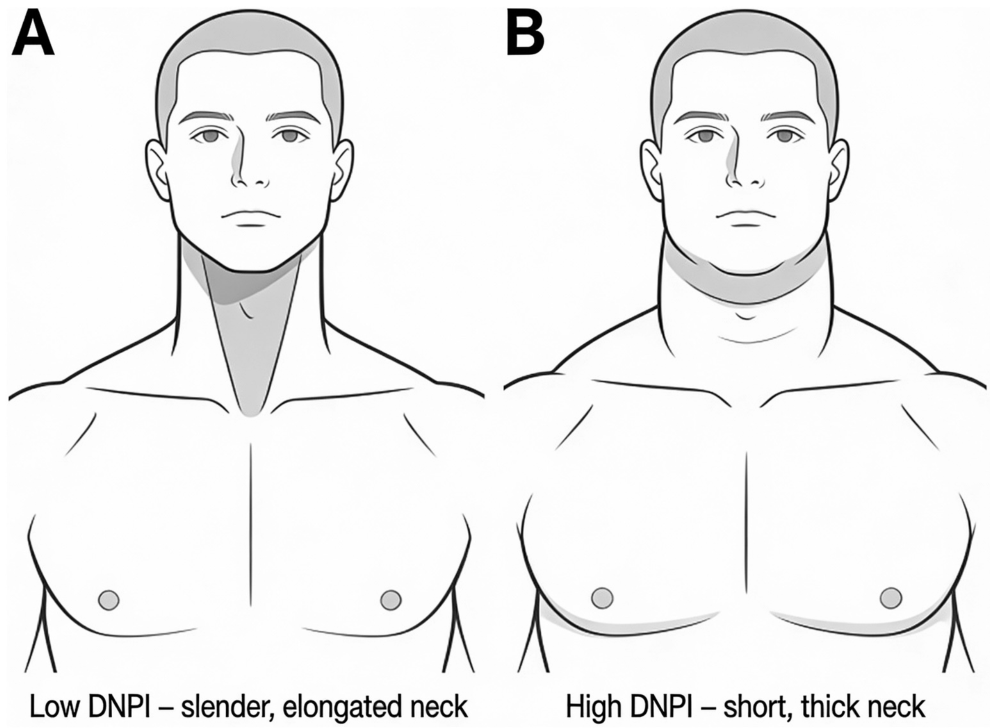

Fig. 2. Simplified Difficult Neck Phenotype Index (DNPI) neck configurations. Panel A shows a low DNPI phenotype, characterized by a slender, elongated neck with a relatively small neck circumference and greater cervicomental height. Panel B shows a high DNPI phenotype, characterized by a short, thick neck with increased soft-tissue bulk, larger neck circumference, and reduced cervicomental height, corresponding to a configuration expected to be associated with more challenging exposure during total thyroidectomy. Fig. 2 is a schematic, conceptual illustration prepared for explanatory purposes and does not represent measured patient data.

that neck configuration is not merely an intuitive impression but a measurable construct with clear operative correlates. By integrating neck circumference and cervicomental height into the DNPI, the analysis shows that a short, thick neck phenotype independently increases intraoperative complexity in total thyroidectomy without leading to higher short-term morbidity in a high-volume specialist setting.

4.1. Neck phenotype and intraoperative complexity

In this cohort, higher DNPI values, reflecting a proportionally shorter and thicker neck, were consistently associated with prolonged operative time, greater need for extended exposure maneuvers (partial strap division, long retractors, lateral incision extension), increased blood loss, and more frequent drain use. These associations persisted after adjustment for age, BMI, thyroid volume, Graves' disease, malignancy, retrosternal extension, and TDS scores, indicating that neck phenotype exerts an independent effect on technical demand beyond disease-related factors and conventional measures of habitus [3,33]. We agree that intrinsic thyroid characteristics are major contributors to operative difficulty and could potentially confound the relationship between neck anatomy and surgical complexity. For this reason, our analyses explicitly included thyroid volume, retrosternal extension, underlying pathology (Graves disease, multinodular goiter, malignancy), and chronic thyroiditis as covariates. DNPI was not associated with these disease-related variables, and its relationship with operative time and exposure maneuvers persisted after multivariable adjustment, supporting the interpretation that the short, thick neck phenotype represents an independent anatomical driver of complexity rather than a surrogate for more challenging gland pathology.

Notably, TDS did not vary across DNPI strata, even though high-DNPI patients required longer operative times and more frequent exposure maneuvers, underscoring that existing difficulty scales may underweight the contribution of neck configuration and emphasizing the added value of DNPI as an anatomy-oriented complement to pathology-driven scoring systems.

Taken together, these findings support the view that DNPI and TDS quantify complementary dimensions of thyroidectomy complexity: DNPI primarily reflects exposure-related anatomical constraints and working angles, whereas TDS remains focused on gland-intrinsic, disease-driven factors. Composite models that integrate both metrics, rather than privileging one over the other, are therefore likely to offer a more faithful representation of global operative difficulty.

Mechanistically, a short, thick neck implies a deeper operative field, reduced working angles, and more substantial soft-tissue retraction to visualize the thyroid lodge and critical structures, providing a plausible anatomical explanation for the observed increases in operating time and resource use [5,35,36].

4.2. DNPI as a pragmatic morphometric metric

A key strength of this work is the use of two simple, low-cost, and widely applicable preoperative measurements – neck circumference and cervicomental height – obtained by anesthetists with the surgeon blinded to raw values, minimizing bias and facilitating reproducibility. DNPI, defined as the ratio of neck circumference to cervicomental height, showed stronger correlations with operative time and intraoperative complexity endpoints than either component alone and yielded better model fit and discrimination in multivariable analyses, supporting the added value of a ratio-based approach that captures global cervical configuration rather than isolated dimensions. Receiver operating characteristic analysis showed moderate discrimination of DNPI for operative time above the 75th percentile (AUC 0.78), and an exploratory cut-off of 4.1 identified patients with approximately three-fold higher odds of prolonged surgery and increased composite intraoperative complexity events, providing a practical starting point for risk stratification, scheduling, and counseling while remaining clearly hypothesis-generating pending external validation [7,37].

Accordingly, DNPI should be regarded as a parsimonious, low-cost

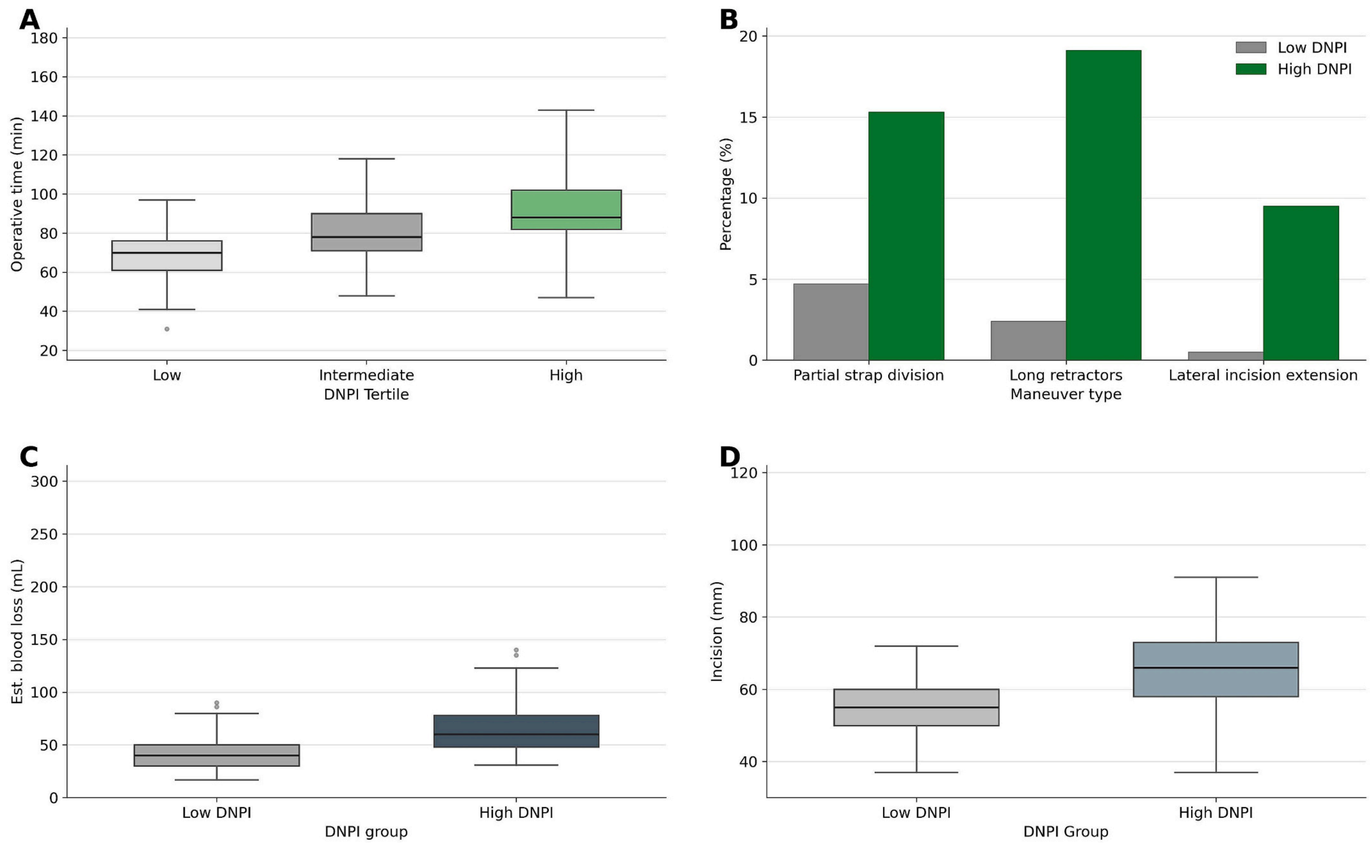

Fig. 3. Impact of neck phenotype on intraoperative complexity. (A) Box-and-whisker plots of operative time across tertiles of the DNPI show progressive prolongation in the high-DNPI tertile. (B) Grouped bar chart showing the proportion of patients requiring extended exposure maneuvers in low versus high DNPI groups, including partial strap muscle division, use of long retractors, and lateral extension of the collar incision. (C) Box-and-whisker plots of estimated intraoperative blood loss by DNPI group demonstrate higher blood loss in patients with a difficult neck phenotype. (D) Box-and-whisker plots of final skin incision length in low and high DNPI groups indicate longer incisions in the high-DNPI group.

Table 2
Postoperative morbidity across neck phenotypes (n = 843).

Outcome	Low DNPI n (%)	Intermediate DNPI n (%)	High DNPI n (%)	Total n (%) (cohort)	p value
Transient RLN palsy	50 (8.9)	51 (9.1)	50 (8.9)	151 (9.0)	0.98
Permanent RLN palsy	4 (0.7)	5 (0.9)	4 (0.7)	13 (0.8)	0.93
Any RLN injury (transient or permanent)	54 (9.6)	56 (10.0)	54 (9.6)	164 (9.7)	0.97
Transient hypocalcemia	64 (22.8)	65 (23.1)	65 (23.1)	194 (23.0)	0.99
Permanent hypocalcemia	7 (2.5)	7 (2.5)	6 (2.1)	20 (2.4)	0.95
Postoperative bleeding/ hematoma	3 (1.1)	3 (1.1)	2 (0.7)	8 (1.0)	0.88
Clinically relevant seroma	4 (1.4)	5 (1.8)	4 (1.4)	13 (1.5)	0.93
Wound infection/ dehiscence	3 (1.1)	3 (1.1)	3 (1.1)	9 (1.1)	1.00
Staged completion thyroidectomy	4 (1.4)	4 (1.4)	3 (1.1)	11 (1.3)	0.93
Median postoperative stay, days (IQR)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	0.97

descriptor of neck configuration that augments, rather than replaces, existing clinicopathologic predictors of difficulty. More elaborate models integrating DNPI with imaging-derived measures of cervical depth, soft-tissue thickness, and spinal alignment may achieve higher discrimination and merit formal comparison with DNPI alone.

Table 3
DNPI as an independent predictor of intraoperative surgical risk. DNPI was not an independent predictor of postoperative complications in multivariable models. For operative time > 75th percentile, DNPI showed moderate discrimination (AUC 0.78, 95% CI 0.71–0.84), with an exploratory, ROC-derived cutoff of ≥4.1 (derived and tested within the same dataset, without internal resampling or external validation) yielding 76.3% sensitivity and 68.5% specificity. This cutoff is hypothesis-generating and should not be used as a stand-alone clinical decision threshold.

Outcome (per 1-unit DNPI increase)	Adjusted OR	95% CI	p value
Prolonged operative time (>75th percentile)	2.15	1.52–3.06	<0.001
Use of surgical drains	1.72	1.18–2.50	0.005
Use of long/enhanced retractors	1.89	1.30–2.76	0.001
Lateral extension of collar incision	1.64	1.05–2.55	0.03
Greater intraoperative blood loss	1.58	1.10–2.29	0.01

Footnote: All models are multivariable logistic regressions adjusted for DNPI, age, BMI, thyroid volume, Graves' disease, malignancy, and retrosternal extension; component measurements (NC and CMH) were not co-entered with DNPI. OR = odds ratio; CI = confidence interval; AUC = area under the receiver operating characteristic curve. Discrimination for prolonged operative time: AUC 0.78 (95% CI 0.71–0.84). Complete model outputs (all covariate estimates, 95% CIs, and calibration) are provided in the Supplementary Material.

4.3. Independence from thyroid pathology and global habitus

DNPI, neck circumference, and cervicomental height were not significantly associated with underlying thyroid diagnosis, thyroid volume, retrosternal extension, or chronic thyroiditis, suggesting that the measured neck phenotype primarily reflects patient habitus rather than intrinsic gland characteristics. The analysis of DNPI–BMI relationships further indicates that neck configuration is not simply a surrogate for overall adiposity: although obesity and male sex were associated with higher DNPI, the index retained independent predictive value for intraoperative complexity after adjustment for BMI and other confounders. These findings underscore the clinical relevance of a region-specific anthropometric measure; relying solely on BMI as a proxy for difficulty may underestimate the impact of unfavorable cervical anatomy, whereas incorporating DNPI into preoperative assessment could refine case selection and enhance the granularity of risk communication and benchmarking [6,35].

Notably, when BMI and thyroid volume were included in multivariable models, DNPI maintained a stronger and more consistent association with operative time and exposure maneuvers than BMI alone, supporting its added value as a region-specific, neck-focused descriptor rather than a simple surrogate for global adiposity.

4.4. Postoperative morbidity and safety considerations

Despite its strong association with intraoperative complexity and process-related endpoints, DNPI did not independently predict postoperative complications, including transient or permanent recurrent laryngeal nerve palsy, hypocalcemia, cervical hematoma, or wound complications. Complication rates remained low and comparable across DNPI strata, and odds ratios in multivariable models were close to unity with wide confidence intervals, suggesting that in a high-volume, guideline-driven environment with routine neuromonitoring and standardized parathyroid-preservation strategies, the additional technical burden imposed by a difficult neck phenotype can be absorbed without compromising short-term safety. However, the limited number of rare events (e.g., hematoma, permanent RLN palsy, permanent hypocalcemia) reduces statistical power, and these reassuring results may not be directly generalizable to lower-volume settings, more complex procedures (such as reoperations or lymphadenectomy), or advanced remote or minimally invasive approaches, where anatomical constraints could have a greater impact on complication risk [8,34].

In particular, the wide confidence intervals around the odds ratios for cervical hematoma, permanent recurrent laryngeal nerve palsy, and permanent hypocalcemia indicate considerable statistical imprecision, and therefore preclude excluding clinically relevant increases in risk among patients with a difficult neck phenotype. Thus, our findings should be viewed as reassuring within a highly standardized, high-volume environment, but they do not establish non-inferiority of high-DNPI necks with respect to postoperative morbidity, especially in lower-volume or less structured settings.

4.5. Clinical implications and future directions

such as TDS. In practical terms, DNPI could guide the allocation of challenging cases to more experienced surgeons, the organization of operating room lists and resource planning, and more realistic counseling regarding anticipated operative time, incision length, exposure maneuvers, and potential need for drains, with implications for efficiency, costs, and training. In selected patients in whom an unfavorable neck phenotype is expected to compromise exposure, this information may also inform shared decision-making about the extent of resection — for example, considering a more limited operation such as hemithyroidectomy where oncologically and clinically appropriate — as one means of mitigating technical risk. Additionally, within the limits of this single-center, single-surgeon dataset, DNPI may also offer a candidate morphometric metric for stratification in clinical trials and registries and may be especially valuable in studies of techniques and technologies whose performance is sensitive to cervical configuration, including reoperative surgery, central and lateral neck dissection, and endoscopic or robotic approaches that were not included in this cohort. Future multicenter research should validate DNPI across diverse ethnicities, BMI distributions, and institutional volumes, evaluate its performance in more complex operations, and explore its incorporation into composite risk models and cost-effectiveness analyses linking neck phenotype to operating time, resource utilization, and long-term outcomes [3–8].

Even without a proven association with complications, the ability of DNPI to anticipate prolonged operative time, more extensive exposure, and greater resource use has practical relevance for case allocation, operating room scheduling, team preparation, and training. The consistent correlation between DNPI and more objective, less discretionary indicators such as operative time and blood loss further suggests that the index is capturing a genuine anatomical signal that persists beyond local variations in exposure and drainage policies.

Beyond its association with intraoperative complexity, the clinical value of DNPI will ultimately depend on how neck phenotype influences outcomes that matter directly to patients and healthcare systems. Future studies should therefore include DNPI in analyses of patient-reported quality of life, cosmetic satisfaction, and functional recovery, as well as formal evaluations of resource utilization, operating room efficiency, and cost-effectiveness. Incorporating DNPI into prospective registries and trial frameworks could help determine whether difficult neck phenotype leads to measurable differences in long-term patient experience and economic burden, thereby defining its role in routine preoperative counseling and institutional planning.

Future work should also evaluate composite predictive models that integrate DNPI with BMI, thyroid volume, and standardized airway assessment variables to quantify the incremental gain in discrimination and calibration for both intraoperative complexity and postoperative morbidity.

In this context, surgeon experience and technique are central determinants of how increased anatomical complexity is managed. All procedures in the present series were performed in a high-volume endocrine surgery unit by a single, experienced endocrine surgeon operating within standardized institutional protocols, including routine intraoperative neuromonitoring and structured parathyroid-preservation strategies. This deliberate homogeneity strengthens internal validity by minimizing variability related to learning curves and operator-specific preferences, thereby helping to isolate the specific contribution of neck phenotype to intraoperative complexity. At the same time, it implies that our findings primarily reflect the performance of DNPI in an optimized specialist environment rather than across the full spectrum of surgical expertise.

Accordingly, the DNPI value of 4.1 should be interpreted only as a preliminary risk marker that requires calibration and validation in independent cohorts with different ethnic compositions, BMI distributions, institutional volumes, and case mixes, including reoperations, lymphadenectomies, and remote or endoscopic approaches. Until such external validation is available, DNPI – and particularly this cut-off – should not be used as a stand-alone criterion for case allocation, performance benchmarking, or guideline-level recommendations, but rather as an adjunctive descriptor of neck anatomy alongside established clinical and pathological predictors.

As a consequence, our results cannot be directly extrapolated to reoperative thyroidectomy, central or lateral neck dissection, or remote and minimally invasive approaches, in which scar tissue, altered landmarks, and constrained working spaces may amplify the influence of a short, thick neck on both intraoperative complexity and complication risk. Targeted multicenter studies in these higher-risk scenarios are warranted to test the external validity of DNPI and its potential interaction with procedure type.

4.6. Study limitations

The limitations of this study should be interpreted hierarchically, with those affecting generalisability and complication endpoints being most critical, followed by measurement and analytical constraints. First, the single-center, high-volume, single-surgeon design ensures internal consistency but limits generalisability to lower-volume or non-specialist settings, where difficult neck anatomy may have a greater impact. Second, despite a cohort of 843 consecutive total thyroidectomies, the observational design precludes causal inference and cannot exclude residual confounding from unmeasured factors such as positioning, chest-wall and breast habitus, soft-tissue variability, or surgeon preference. Third, neck phenotype was assessed using single-time-point manual measurements (neck circumference and cervicomental height) without formal intra- or inter-observer reproducibility testing and without imaging-derived parameters, which could improve anatomical characterization. Fourth, several complexity surrogates (e.g. long retractors, incision extension, drain use), although anatomically related, are partly influenced by surgeon judgement and institutional practice, so associations with DNPI may reflect context-specific responses rather than purely anatomical constraints. Fifth, the study was underpowered for rare complications (cervical).

5. Conclusions

This study demonstrates that a short, thick neck phenotype, quantified by the Difficult Neck Phenotype Index (DNPI), is an independent anatomical determinant of intraoperative complexity in total thyroidectomy, without a detectable increase in short-term postoperative morbidity in a high-volume setting, although power for rare complications was limited. DNPI provides a simple, low-cost morphometric metric that helps objectify the traditionally subjective concept of a “difficult neck.” In its present form it is an exploratory, internally derived marker; before it can be recommended for routine risk stratification, operative planning, or benchmarking, its reproducibility and predictive performance require confirmation across operators, centres, and populations. Further multicenter studies across diverse populations, institutional volumes, and surgical techniques are warranted to validate DNPI thresholds and assess generalizability.

Reporting guideline

This observational study is reported in accordance with the STROBE statement, and a completed STROBE checklist is provided as Supplementary Material.

CRediT authorship contribution statement

Daqi Zhang: Writing – review & editing, Conceptualization. **Francesco Brucchi:** Writing – original draft, Formal analysis. **Carla Colombo:** Writing – review & editing, Visualization. **Hoon Yub Kim:** Writing – review & editing, Supervision. **Alessandro Bacuzzi:** Writing – review & editing, Visualization. **Gianlorenzo Dionigi:** Writing – original draft, Conceptualization.

Informed consent

Written informed consent was obtained from all individual participants included in this study.

Ethics approval

This study was approved by the local Institutional Review Board (Protocol No. 2.792.420) and conducted in accordance with the Declaration of Helsinki.

Declaration of Generative AI and AI-assisted technologies in the writing process

We disclose that ChatGPT (OpenAI) was used during manuscript preparation solely for language editing, readability improvement, and refinement of phrasing. No AI tool was used to generate scientific ideas, interpret results, or draw conclusions. All output was critically reviewed and edited by the authors, who take full responsibility for the final content.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjoto.2026.104891.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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