

Long-term Oncologic Outcomes and Prognostic Determinants of Transoral Coblation Surgery for Early-Stage Laryngeal Cancer

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Abstract: Background: Transoral coblation surgery has emerged as a promising minimally invasive modality for early-stage laryngeal cancer, characterized by superior intraoperative hemostasis and favorable postoperative voice function recovery. Nevertheless, high-quality evidence regarding its long-term oncologic outcomes, derived from large-scale cohorts, remains scarce. The present study aimed to assess survival outcomes, prognostic factors, and functional preservation in the largest reported cohort of patients treated with this technique.

Methods: A retrospective cohort study was conducted, encompassing 444 patients with Tis-T2N0M0 laryngeal cancer who underwent transoral coblation surgery at a single institution between 2013 and 2021. Primary endpoints included disease-free survival (DFS), overall survival (OS), and laryngeal preservation rate (LPR). Kaplan-Meier methods with log-rank tests were utilized to compare survival curves, while Cox proportional hazards models were employed to identify predictors of recurrence. Multivariate analyses were performed to adjust for covariates with a significance level of $p < 0.1$ in univariate screening. Sex was excluded from multivariate modeling due to substantial gender imbalance within the cohort (male:female ratio = 21:1) and an insufficient number of recurrence events among female patients ($n < 5$).

Results: With a median follow-up duration of 79 months (range: 36–144 months), the cohort exhibited a 5-year OS of 89.1% (95% confidence interval [CI]: 86.2–92.2), a 5-year DFS of 80.7% (95% CI: 77.1–84.6), and an LPR of 98.2%. Multivariate analysis confirmed that advanced T-stage (hazard ratio [HR] = 1.37, 95% CI: 1.09–1.71, $P = 0.006$) was an independent predictor of recurrence. Anterior commissure involvement was associated with postoperative recurrence in univariate analysis (HR = 1.87, $P = 0.007$) but failed to retain statistical significance after multivariate adjustment ($P = 0.184$). A significant improvement in survival outcomes was observed for procedures performed after 2018 (OS: 94.8% vs. 85.0%, $P = 0.001$), indicative of a learning curve effect. Salvage coblation achieved disease control in 21 out of 22 patients with early recurrence (95.5%).

Conclusion: The present study, featuring the largest cohort to date ($n = 444$), confirms that transoral coblation represents a viable function-preserving therapeutic strategy for early-stage laryngeal cancer, with 5-year outcomes com-

parable to those of established surgical modalities. While T-stage is a robust predictor of recurrence, anterior commissure involvement warrants meticulous technical management and optimized preoperative imaging protocols. Surgical proficiency exerts a significant impact on outcomes, underscoring the necessity of standardized training to maximize oncologic efficacy.

Keywords: Transoral Coblation Surgery; Early-Stage Laryngeal Cancer; Oncologic Outcomes; Prognostic Factors; Cohort Study

INTRODUCTION

Laryngeal squamous cell carcinoma (LSCC) accounts for approximately 25% of all head and neck tumors^[1], with excessive tobacco and alcohol use serving as primary risk factors; its incidence has been declining in recent years, largely due to increased public awareness of these risk factors^[2]. For early-stage laryngeal cancer (LC), multiple therapeutic strategies are available, though patient preferences alongside social, cultural, and economic backgrounds significantly influence treatment selection alongside medical recommendations^[3]. The Union for International Cancer Control (UICC) identifies the primary debate regarding treatment strategies for stage I and II glottic carcinoma (T1, T2, N0) as centering on the optimal choice between single-modality therapy—either surgery or radiotherapy.

LC typically arises in three anatomical subsites: the supraglottis, glottis, and subglottis. The supraglottic region encompasses the epiglottis, arytenoid cartilages, aryepiglottic folds, and false vocal cords. The glottis comprises the true vocal cords, while the subglottis extends from the inferior border of the true vocal cords to the lower margin of the cricoid cartilage^[4]. According to the 1997 UICC clinical staging criteria for LC, glottic carcinoma stages Tis to T2 are classified as early-stage glottic carcinoma. T1 lesions involve a single subsite within each anatomical region, whereas T2 lesions demonstrate extension to an adjacent subsite; for instance, a T2 lesion in the supraglottis not only affects the epiglottis but also extends to neighboring structures such as the cricoarytenoid joint. T1 glottic lesions are further subdivided into T1a (unilateral vocal cord involvement) and T1b (bilateral vocal cord involvement), with the glottis being the most commonly affected subsite (87.8%), followed by the supraglottis (10.9%) and subglottis (1.4%)^[5]. The selection of clinical treatment strategies depends on the tumor location and the extent of involvement at that site. Primary therapeutic modalities encompass radiotherapy or surgical interventions such as transoral laser microsurgery, transoral robotic surgery, or open partial laryngectomy. In recent years, radiofrequency coblation has been gradually applied in endoscopic laryngeal surgery^[6]. Nevertheless, multiple studies have demonstrated that this technique offers advantages including minimal invasiveness, reduced intraoperative bleeding, shorter operative duration, and rapid postoperative voice recovery[7, 8]. However, large-scale data regarding long-term survival outcomes and prognostic

risk factors remain limited. This retrospective analysis examined postoperative outcomes in 444 patients with primary early-stage glottic carcinoma treated with coblation surgery. The primary objectives were to further evaluate the prognostic implications of coblation surgery for early-stage LC and assess the influence of relevant risk factors on disease-free survival (DFS), thereby identifying determinants of therapeutic efficacy and deriving clinically actionable insights from the findings.

1. DATA and METHODS

1.1 Ethics Statement

The study was conducted in compliance with the Declaration of Helsinki. All patients provided written informed consent for sample collection and analysis. Ethical approval was obtained from the Institutional Review Board of the First Affiliated Hospital of Nanjing Medical University (Approval No.: 2020-NT-08).

1.2 Study Subjects

A retrospective analysis was conducted on clinical data from 480 patients with early-stage LC who underwent transoral endoscopic coblation surgery (TRCS) at our institution between April 2013 and December 2021. 36 patients lost to follow-up were excluded, resulting in a final cohort of 444 patients. All patients received no prior treatment before surgery, with malignancy confirmed via preoperative biopsy or intraoperative frozen section. Postoperative follow-up included routine electronic laryngoscopy and neck CT scans. This study was conducted in accordance with the Declaration of Helsinki and received approval from the Ethics Committee of The First Affiliated Hospital with Nanjing Medical University.

1.3 Case screening criteria and characteristic

Inclusion criteria comprised: (1) histologically confirmed early-stage LC; (2) absence of lymph node or distant metastasis on preoperative imaging; (3) preoperative or intraoperative clinicopathological diagnosis of squamous cell carcinoma; (4) primary treatment with transoral coblation surgery (TRCS) at our institution; (5) availability of complete clinical records.

Exclusion criteria encompassed: (1) receipt of neoadjuvant or adjuvant chemotherapy/radiotherapy; (2) concurrent pharyngeal or laryngeal comorbidities; (3) diagnosis with synchronous primary malignancies.

The following demographic and clinicopathological characteristics were retrospectively extracted from medical records: gender, age, T-stage, year of surgery, smoking history, alcohol consumption, anterior commissure involvement, recurrence status, time to recurrence, specific retreatment modalities upon recurrence, mortality status, and cause-specific mortality.

1.4 Research Methods

1.4.1 Surgical Equipment

Procedures utilized the CoblatorII low-temperature plasma radiofrequency system (USA), Reflex 70-gauge coblation wand, STORZ laryngoscopes, 12° laryngeal endoscopes, and compatible video imaging systems.

1.4.2 Preoperative Assessment

All patients underwent preoperative electronic laryngoscopy, cervical CT, and/or MRI to evaluate tumor size, vocal cord mobility, and local invasion. Patients exhibiting vocal cord fixation, paraglottic space invasion, thyroid cartilage involvement, or suspected lymph node metastasis were excluded.

1.4.3 Surgical Technique

Surgeries were performed under general anesthesia with orotracheal intubation. Patients were positioned supine, and laryngoscopes were inserted transorally to fully expose the glottis (particularly the anterior commissure) and tumor margins. Under endoscopic visualization, tumors were retracted contralaterally and resected with a minimum 3-mm margin. Intraoperative frozen sections were obtained from at least five sites (superior, inferior, anterior, posterior, and deep margins). Negative margins concluded the procedure; positive margins necessitated further resection until margins were clear. Broad-spectrum antibiotics were administered solely on the day of surgery to prevent infection, while postoperative corticosteroid nebulization was routinely employed to mitigate vocal cord edema.

1.4.4 Postoperative Follow-up

Patients were evaluated monthly for the first 6 months, quarterly from 6 months to 2 years, and biannually from 2 to 5 years. Telephone follow-ups supplemented missed appointments. The follow-up endpoint was August 31, 2023, with a follow-up duration ranging from 36 to 144 months (median: 79 months).

1.5 Observational index

In terms of evaluation indicators, first, vocal function assessment was performed: a multi-channel acoustic analyzer (produced by Shanghai Huanxi Medical Devices Co., Ltd.) was used. In a quiet environment with noise below 45 dB, the microphone was placed 30 cm away from the patient's mouth, and the patient was instructed to continuously produce the vowel "a". Acoustic parameters such as jitter (amplitude perturbation), shimmer (fundamental frequency perturbation), fundamental frequency, and harmonic-to-noise ratio were recorded simultaneously. Second, pain level assessment was conducted: the Visual Analogue Scale (VAS) was adopted to quantify the patient's pain level before and after treatment. The total score of this scale ranges from 0 to 10, with a higher score indicating more significant pain perception of the patient. Third, vocal cord morphological

scoring was carried out: laryngoscopy was performed to observe the vocal cord morphology and score it before and after treatment, with the scoring standard ranging from 0 to 3. A score of 0 indicates that the vocal cords and mucosa are in a normal state, while a score of 3 corresponds to obvious congestion and swelling of the vocal cords, accompanied by pseudomembrane formation and granulation hyperplasia on the surface. Generally, a higher score suggests more severe morphological changes of the patient's vocal cords.

1.6 Statistical Analysis

Data analysis and visualization were performed using R software (version 4.4.2). Survival analysis employed the Kaplan-Meier method with curve comparisons assessed via the log-rank test (95% CI reported). Cox proportional hazards regression models were implemented to identify recurrence-associated factors, including univariate analysis of clinicopathological variables and multivariate analysis adjusting for covariates with $p < 0.1$ in univariate screening. Given significant sex imbalance in cohort distribution (male:female ratio = 21:1) and limited recurrence events among female patients ($n < 5$), sex was excluded from Cox modeling to prevent statistical instability from sparse event data. Oncologic outcomes included disease-free survival (DFS), overall survival (OS), and laryngeal preservation rate (LPR). Statistical significance was defined as $P < 0.05$, with hazard ratios (HR) and 95% confidence intervals reported for Cox analyses.

3. RESULTS

1. Baseline Characteristics of the Study Cohort

The study cohort comprised 444 patients with glottic carcinoma who underwent coblation surgery at our institution between April 2013 and December 2021. Demographic analysis revealed a male predominance ($n=424$) compared to female patients ($n=20$). Age distribution ranged from 38 to 90 years, with a median age of 65 years, the cohort was stratified by age into two subgroups: patients aged ≥ 65 years ($n=237$) and those aged < 65 years ($n=207$). Tumor staging according to the TNM classification included Tis ($n=92$), T1 ($n=240$; T1a=137, T1b=103), and T2 ($n=112$) lesions. Anterior commissure involvement was documented in 240 cases, while 204 tumors spared this anatomical site. Surgical intervention occurred in 254 cases prior to 2018, while 190 cases underwent procedures after 2018. Detailed clinicopathological characteristics are presented in **Table 1**.

Preoperative evaluation confirmed absence of cervical lymph node and distant metastasis in all 444 early-stage LC patients. Among them, 361 cases achieved favorable surgical outcomes during the 36- to 144-month follow-up period, with no documented local recurrence, distant metastasis, or severe postoperative complications such as hemorrhage or dyspnea. While patients with Tis and T1 tumors exhibited satisfactory vocal recovery, those with T1b and T2 lesions

demonstrated clinically significant vocal fold adhesions and consequent vocal impairment due to anterior commissure proximity of surgical defects.

Postoperative Outcomes

The study cohort included patients with T1a LC who underwent coblation surgical excision (Fig 1A). Intraoperatively, the procedure involved complete unilateral resection of the vocal fold down to the level of the vocalis muscle. Postoperative surveillance revealed a consistent pattern of wound healing: 1 week after surgery, granulation tissue formation with pseudomembrane attachment was observed (Fig 1B); by 1 month, the pseudomembrane began gradually shedding; at 2 months, the pseudomembrane had nearly completely resolved, with scar tissue formation on the wound surface; and by 6 months (Fig 1C), the vocal fold appearance had stabilized, remaining unchanged through the 3-year follow-up period (Fig 1D).

Cohort Survival Analysis

At the final follow-up endpoint, 83 of 444 patients experienced recurrence, including one case recurring at 5 years postoperatively, yielding an overall 5-year recurrence rate of 18.5%. Among 46 recorded deaths, causes included: 20 cardio-pulmonary-related deaths, 5 deaths from complications following salvage surgery for recurrent disease, 5 treatment-related deaths during management of recurrence, 6 deaths from secondary malignancies, 2 hemorrhage-related deaths from recurrent tumors, 2 respiratory failure deaths from recurrent disease, 1 cholecystitis-related death, 1 malnutrition-related death due to dysphagia, and 4 deaths from undetermined causes. The cohort demonstrated DFS rates of 89.5% (95% CI: 86.7–92.4), 85.8% (95% CI: 82.6–89.1), and 80.7% (95% CI: 77.1–84.6) at 1, 2, and 5 years postoperatively, respectively. Corresponding OS rates were 97.1% (95% CI: 95.5–98.6), 93.7% (95% CI: 91.4–96.0), and 89.1% (95% CI: 86.2–92.2) for the same intervals.

Subsequent analyses evaluated the impact of various clinicopathological factors—including gender, age, T-stage, anterior commissure involvement, smoking status, alcohol consumption, and surgical period—on overall patient prognosis. The analysis of five-year survival outcomes identified several key factors with statistically significant impacts while noting others that showed trends without reaching significance. Tumor stage demonstrated the strongest prognostic influence, with Tis cases showing superior survival (OS 97.8%, DFS 88.1%, LPS 100%) compared to advanced stages like T2 (OS 79.6%, DFS 72.1%, LPS 98%), with significant P-values (OS $P < 0.001$, DFS $P = 0.003$). Anterior commissure involvement significantly worsened outcomes, with involved cases showing lower survival rates (OS 86.2%, DFS 76.2%, LPS 97.4%) versus uninvolved cases (OS 92.5%, DFS 86.1%, LPS 99.5%; DFS/LPS $P = 0.006$). Surgical period demonstrated superior survival outcomes for procedures performed post-2018 compared to pre-2018, with post-2018 cohorts achieving 94.8% OS, 86.0% DFS, and 96.8%

LPR. Statistical significance was confirmed for OS ($P=0.001$), DFS ($P=0.032$) and LPR ($P=0.001$), indicating that less refined surgical techniques during earlier periods may have adversely impacted patient prognosis. While sex, smoking history, and alcohol consumption showed numerical differences in survival rates, these did not reach statistical significance. Regarding age stratification, statistically significant differences were observed solely in OS ($p=0.018$), with patients aged ≥ 65 years exhibiting an 85.6% survival rate that was significantly inferior to the 93.0% rate among those <65 years. DFS and LPS demonstrated no statistically significant disparities between age cohorts. Detailed outcomes presented in Table 2.

Results of Cox Regression Analysis for Predicting Recurrence

The univariate Cox regression analysis revealed that T-stage, and anterior commissure involvement were significant predictors of recurrence in LC patients. Specifically, anterior commissure involvement was strongly correlated with recurrence risk (HR = 1.87, 95% CI: 1.18–2.97, $P = 0.007$). Furthermore, higher T-stage was also found to increase recurrence risk (HR = 1.46, 95% CI: 1.19–1.79, $P < 0.001$). In contrast, age (HR = 1.01, 95% CI: 0.99–1.03, $P = 0.446$), smoking status (HR = 1.25, 95% CI: 0.75–2.09, $P = 0.386$) and alcohol consumption (HR = 1.19, 95% CI: 0.77–1.83, $P = 0.427$) were not significantly associated with recurrence (Fig 4A).

Multivariate Cox regression analysis confirmed that T-stage remained independent predictors of recurrence risk. Higher T-stage was significantly associated with an increased risk of recurrence (HR = 1.37, 95% CI: 1.09–1.71, $P = 0.006$). Age (HR = 1.01, 95% CI: 0.99–1.03, $P = 0.470$), smoking (HR = 1.12, 95% CI: 0.64–1.98, $P = 0.688$), alcohol consumption (HR = 1.20, 95% CI: 0.75–1.93, $P = 0.455$), and anterior commissure involvement (HR = 1.40, 95% CI: 0.85–2.30, $P = 0.184$) were not statistically significant predictors of recurrence in multivariate analysis, suggesting these factors may not independently contribute to the risk of recurrence when adjusted for other covariates (Fig 4B).

Recurrent Patient Outcomes

Among the 83 recurrent cases, 9 exhibited indeterminate T-stage at recurrence, while the distribution included T1a ($n=8$), T1b ($n=4$), T2 ($n=18$), T3 ($n=23$), and T4 ($n=20$), with one patient demonstrating isolated cervical lymph node metastasis without laryngeal recurrence. Management strategies varied according to recurrent T-stage: one T1a patient underwent radiotherapy, two T1b patients received frontolateral partial laryngectomy, and six T2 patients underwent partial laryngeal procedures (including vertical hemilaryngectomy and cricohyoidoepiglottopexy). The majority of recurrent cases underwent salvage radiofrequency coblation, with postoperative follow-up ranging from 12 to 110 months (median 56 months). Among these coblation-treated patients, only one case experienced subsequent recurrence after self-elected adjuvant radiotherapy and ultimately

succumbed to radiotherapy complications; all others remained recurrence-free during surveillance. Treatment approaches for advanced recurrences included radiotherapy alone for five T3 and two T4 cases, chemotherapy alone for two T3 cases due to comorbidities, partial laryngectomy for eight T3 cases, and total laryngectomy for six T3 and sixteen T4 cases. The isolated nodal recurrence received neck dissection, while thirteen patients received no further treatment. During follow-up, 23 of the 83 treated recurrent patients died, with detailed outcomes presented in Table 3.

Comparison of voice functions

As shown in Table 4, compared with the preoperative period, the amplitude perturbation, fundamental frequency perturbation, and fundamental frequency of patients significantly decreased after treatment, with statistically significant differences ($P < 0.05$, Table 4). However, there was no significant difference in the harmonic-to-noise ratio before and after treatment ($P > 0.05$).

VAS score and vocal cord morphology score

As indicated in Table 5, compared with the preoperative period, the Visual Analogue Scale (VAS) scores and vocal cord morphological scores in the observation group decreased extremely significantly after treatment, with statistically significant differences ($P < 0.05$, Table 5).

4. DISCUSSION

Since the 1990s, the focus of LC treatment has shifted considerably towards function-preserving techniques, with a strong preference for minimally invasive surgical approaches that aim to maximize the preservation of residual function and optimize patients' postoperative quality of life^[7]. This paradigm shift reflects the growing emphasis on balancing oncological control with the maintenance of critical laryngeal functions, such as voice, swallowing, and airway protection. The adoption of these organ-sparing strategies has been driven by advancements in surgical instrumentation and techniques, as well as a deeper understanding of the complex interplay between tumor characteristics, treatment modalities, and long-term functional outcomes. Careful patient selection and multidisciplinary treatment planning are essential to ensure the optimal balance between oncological efficacy and functional preservation for individuals diagnosed with early-stage laryngeal malignancies.

The 2018 American Society of Clinical Oncology (ASCO) clinical practice guideline for LC management recommends that T1 and T2 stage disease can be treated with either radiotherapy or function-preserving surgical approaches, as these modalities demonstrate comparable survival outcomes^[9]. This is particularly relevant for patients with high vocal demands, as surgery may yield inferior voice preservation compared to radiotherapy^[10]. However, the guideline also acknowledges that radiotherapy can potentially lead to chronic swallowing dif-

ficulties^[11] and may exacerbate or accelerate vascular pathology, such as carotid artery atherosclerosis progression^[12]. These treatment-related toxicities should be carefully weighed against the functional benefits when selecting the optimal management strategy for early-stage LC patients. Currently, CO₂ laser surgery is the primary surgical approach for the management of early-stage LC. This technique offers several advantages, including a shorter healing process, lower complication rates, and favorable functional outcomes. Additionally, in cases of positive surgical margins, recurrence, or after prior radiation or chemoradiation therapy, the CO₂ laser allows for repeat resection^[13, 14]. However, the CO₂ laser approach does require extensive exposure of the laryngeal structures, and the inherent inability of the laser to bend limits the ease of accessing the anterior commissure region. These technical considerations should be carefully weighed when selecting the optimal treatment modality for individual patients with early-stage laryngeal malignancies.

It is worth noting that radiofrequency coblation is an emerging proprietary technology that was approved by the United States Food and Drug Administration for clinical use in 2000^[15]. In recent years, this modality has seen widespread application in the field of otolaryngology-head and neck surgery, particularly in the realm of minimally invasive LC management^[6]. The underlying principle of cold plasma is the generation of bipolar radiofrequency energy, which rapidly dehydrates cells at low temperatures to achieve precise cutting effects. Concurrently, the technology also exerts hemostatic properties, thereby minimizing the impact of bleeding on the surgical field, especially within the confined laryngeal space^[16]. This allows for clear visualization and accurate targeting of the lesion, ultimately enhancing the therapeutic efficacy of the procedure.

For early-stage LC, both definitive radiotherapy and surgical intervention (e.g., CO₂ laser) represent viable treatment options, with studies suggesting marginally superior outcomes for laser surgery over radiotherapy, though this advantage has diminished with advances in intensity-modulated radiotherapy (IMRT)^[17, 18]. Significant inter-study heterogeneity persists, potentially attributable to institutional biases and operator-dependent decision-making. A recent comparative analysis demonstrated 5-year OS of 84.5% and LCR of 77.2% for CO₂ laser versus 79.4% OS and 71.6% LCR for radiotherapy, with statistically significant differences favoring laser therapy^[17]. Conversely, another study reported 2-year DFS rates of 91.7% (T1a), 66.7% (T1b), and 53.9% (T2) following CO₂ laser resection^[19], underscoring the variability in published outcomes. Our preliminary investigations established T-stage as an independent prognostic determinant in LC, with current oncological data demonstrating a statistically significant declining gradient in survival outcomes from Tis through T1a, T1b, and T2 lesions via Kaplan-Meier analysis, yielding aggregate overall and disease-free survival rates of !!!!!, consistent with extant literature; nevertheless, randomized controlled trials remain imperative for definitive elucidation of comparative therapeutic efficacy. Significant heterogeneity in recurrence rates was identified across operators

in our clinical cohort, underscoring the imperative for structured proficiency development in transoral coblation surgery techniques. The bulky coblation probe complicates precise margin delineation and avoidance of intralesional cutting in confined surgical fields. Yet once the dissection plane is identified, simultaneous cutting and coagulation minimizes hemorrhagic interference, enabling en bloc resection. Moreover, even for the same surgeon, surgical outcomes may demonstrate significant temporal variations across different procedural periods, reflecting evolving technical proficiency and contextual factors influencing operative efficacy. Longitudinal follow-up in this study revealed that among 83 recurrent cases, 57 recurrences originated from patients undergoing initial surgery prior to 2018, with Kaplan-Meier analysis demonstrating statistically significant differences in both DFS and OS between chronological cohorts, substantiating the substantial impact of the surgeon's learning curve on postoperative oncological outcomes.

While extant literature identifies sex and age dichotomized at 60 years as independent prognostic factors in early-stage LC^[20, 21], our analysis revealed no significant differences in survival outcomes by these parameters via Kaplan-Meier curves (**Fig 2A, 2C** and **Fig 3A, 3C**). Notably, age stratification at 65 years demonstrated significant divergence in OS—though DFS remained statistically comparable (**Fig 2B, 3B**). This discrepancy may be attributable to age-related declines in immune function, increased comorbidity burden, and reduced treatment tolerance.^[22] However, when analyzing the relationship between age and recurrence, both univariate and multivariate Cox regression analyses indicated that age was not directly associated with recurrence risk (**Fig 4A-B**). This suggests that while age may influence overall survival through indirect mechanisms, such as comorbidities or treatment-related factors, it does not independently predict the likelihood of postoperative recurrence in LC. Substantial evidence confirms tobacco and alcohol as primary etiological risk factors, with smokers exhibiting 10-15-fold higher LC incidence versus non-smokers^[23], while isolated alcohol consumption confers moderate risk elevation (1.5-2-fold increase, rising significantly with heavy intake ≥ 5 drinks/day)^[24]. Contrary to etiological expectations, our prognostic models indicated no significant impact of smoking or alcohol status on postoperative survival or recurrence (**Fig 2E-F, 3E-F**).

The anterior commissure remains a subject of ongoing debate regarding its role as either a potential pathway or barrier for tumor spread. Anatomically defined as the most anterior glottic region where bilateral vocal cords insert into the thyroid cartilage's intermediate lamina, this area comprises mucosa overlying ligamentous fibers parallel to the thyroid cartilage, bounded superiorly by Broyles' ligament and inferiorly by the conus elasticus. Anterior commissure involvement typically signifies either midline infiltration from unilateral cord tumors or contralateral extension across the glottis. Prevailing evidence indicates that the absence of perichondrium at the anterior commissure ligamentous attachment site facilitates cartilage invasion, as the perichondrium normally serves as a critical

barrier against neoplastic penetration—a protective layer that is characteristically deficient in this specific anatomical region. Current evidence suggests that the fibroelastic architecture of Broyles' ligament confers a protective barrier against tumor progression in early-stage LC; however, it must be emphasized that the caudal termination of this ligament lies precisely superior to the glottic plane, beyond which point it is replaced solely by a comparatively attenuated layer of dense connective tissue. Consequently, at the anterior commissure level, the thyroid cartilage offers no substantive resistance to neoplastic invasion, wherein the mucosa resides in closer proximity to the cartilaginous framework than at any other laryngeal site, thereby exhibiting heightened vulnerability to tumor penetration^[25]. Complementing this anatomical understanding, Rucci delineated four distinct patterns of anterior commissure involvement: AC0 (no involvement), AC1 (unilateral midline involvement), AC2 (partial transmedian extension), and AC3 (bilateral involvement across the midline^[26]). Anterior commissure involvement has been established as an independent predictor of disease recurrence, with recurrence risk demonstrating a positive correlation with escalating grades of anterior commissure invasion per the aforementioned AC classification system^[27]. Our study revealed significantly reduced postoperative DFS in patients with anterior commissure involvement compared to non-involved counterparts ($p < 0.05$), with univariate Cox analysis identifying this anatomical feature as a significant risk factor for recurrence (HR=1.87, 95% CI 1.18-2.97, $P = 0.007$). However, multivariate analysis demonstrated no statistically significant independent association ($P = 0.184$), potentially attributable to confounding effects from laryngeal exposure limitations, inadequate preoperative assessment, and deviations from standardized operative protocols—factors that may obscure true biological relationships through technical variability in surgical execution. Corroborative evidence indicates that glottic-level tumors with preserved cord mobility demonstrate no deep invasion nor penetration of the underlying thyroid cartilage, owing to the protective fibroelastic barrier of Broyles' ligament^[28]. Consequently, mandatory preoperative contrast-enhanced CT with meticulous image interpretation to evaluate thyroid cartilage integrity is recommended for all anterior commissure-involved cases. Comprehensive assessment of anatomical constraints—including interincisal distance, cervical flexion range, cervical muscle tone, and thyromental distance—should precede surgery to evaluate laryngeal exposure feasibility, thereby optimizing therapeutic planning to minimize recurrence risk in this cohort.

Whereas total laryngectomy represented the predominant salvage intervention for recurrent LC over a decade ago^[29], contemporary advancements in endoscopic techniques have established transoral laser microsurgery (TLM) as a viable approach for early-stage recurrences. Comparative analysis of TLM versus open partial laryngectomy (OPL) for recurrent glottic squamous cell carcinoma (rTis-rT2) demonstrated 5-year OS rates of 65.8% ($n = 55$) and 77.1% ($n = 40$), respectively, with corresponding 5-year LPR of 94.4% (TLM) and 83.6% (OPL).

Although statistical significance was not achieved, the marginally superior LPR in the TLM cohort underscores its functional preservation advantage, thereby providing rationale for repeat transoral minimally invasive interventions in early recurrent disease. In alignment with this paradigm, the present study employed coblation surgery for 22 rTis-rT2 recurrent cases, achieving favorable outcomes in all but one fatality attributable to radiotherapy complications. Patients undergoing secondary minimally invasive procedures retain therapeutic alternatives—including OPL, total laryngectomy, or radiotherapy—should further recurrence occur^[30]. Notably, coblation surgery was not universally applied to early recurrent cases in this cohort; beyond patient preference, preoperative determination of anticipated negative margins is imperative, whereby open surgery or radiotherapy constitutes the optimal alternative when margin negativity appears unattainable via repeat plasma intervention.

CONCLUSION

To our knowledge, this investigation represents the largest cohort study to date (n=444; median follow-up 79 months) evaluating long-term outcomes of transoral coblation surgery for early-stage LC. The analysis demonstrates that this technique achieves durable oncologic control, with 5-year OS and DFS rates of 89.1% and 80.7% respectively, while preserving laryngeal function in >97% of patients. Multivariate modeling established T-stage (HR=1.37, 95% CI 1.09–1.71, $P = 0.006$) as independent recurrence predictors. Although anterior commissure involvement associated with postoperative recurrence in univariate analysis (HR=1.87, $P = 0.007$), its loss of significance after covariate adjustment ($P = 0.184$) likely reflects technical challenges inherent to this anatomically complex subsite rather than biological irrelevance – a critical consideration given Broyles' ligament deficiency at this location. The significant survival improvement post-2018 (OS 94.8% vs. 85.0%, $P = 0.001$) underscores the procedure's steep learning curve, emphasizing that optimal outcomes require: 1) preoperative contrast-enhanced CT for anterior commissure tumors to assess cartilaginous integrity, and 2) structured surgical training programs addressing exposure limitations and margin control. This large-scale experience confirms coblation's viability as a primary and salvage modality (95.5% remission in rTis-T2 recurrences), establishing it as a function-preserving alternative within the early LC armamentarium. Future multi-institutional studies should standardize technical protocols to minimize operator-dependent outcome variability.

Conflict of interest

The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

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Author contributions

All authors contributed to the study conception and design. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability

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

Ethics approval

The study was approved by the Institutional Review Board of the First Affiliated Hospital with Nanjing Medical University (2020-NT-08).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

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Table 1. Baseline Characteristics of the Study Cohort (n = 444)

Characteristic	n	%
Sex		
male	424	95.5
female	20	4.5
age		
≥65	237	53.4
<65	207	46.6
T stage		
Tis	92	20.7
T1a	137	30.9
T1b	103	23.2
T2	112	25.2
smoking history		
Yes	325	73.2
No	119	26.8
Alcohol consumption		
Yes	227	51.1
No	217	48.9
anterior commissure involvement		
Yes	240	54.1
No	204	45.9
Surgical Period		
Before 2018	254	57.2
After 2018	190	42.8

Table 2. Five-year survival outcomes for the entire study population

Variables	OS	P	DFS	P	LPS	P
Sex						
Male	88.6	0.128	80.8	0.972	98.2	0.946
Female	100		78.9		100	
Age						
≥65	85.6	0.018	80.7	0.814	97.8	0.056
<65	93		80.7		98.9	
T stage						
Tis	97.8	<0.001	88.1	0.003	100	0.125
T1a	94		85.8		98.3	
T1b	85.9		76.4		97.2	
T2	79.6		72.1		98	
smoking history						
Yes	89.1	0.916	79.9	0.386	98.2	0.073
No	89.2		83.1		98.7	
Alcohol consumption						
Yes	89.4	0.886	79.7	0.433	97.4	0.389
No	88.8		81.7		99.3	
anterior commissure involvement						
Yes	86.2	0.06	76.2	0.006	97.4	0.006
No	92.5		86.1		99.5	
Surgical Period						
Before 2018	85	0.001	77.2	0.032	98.7	0.001
After 2018	94.8		86		96.8	

Table 3 Post-Recurrence Patient Outcomes

Post-Recurrence Management	Post-Progression T-Stage						UnK	Death cases
	T1a	T1b	T2	T3	T4	LNR		
Salvage coblation	7	2	12					1
Partial Laryngectomy		2	6	8				3
Total Laryngectomy				6	16			3
Isolated Neck Dissection						1		1
Radiotherapy Alone	1			5	2			5
Chemotherapy Alone				2				2
Treatment Abandonment				2	2		9	8

LNR: Lymph Node Recurrence; Unk: Unknown

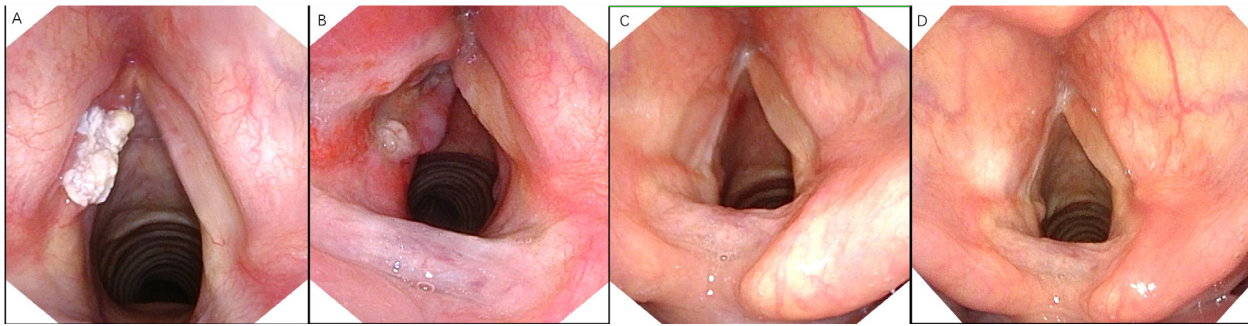


Fig 1. Coblation Surgery for Laryngeal Cancer: Pre- and Postoperative Follow-up. (A) Pre-operation. (B) One week after the operation. (C) Six months after the operation. (D) 44 months after the operation.

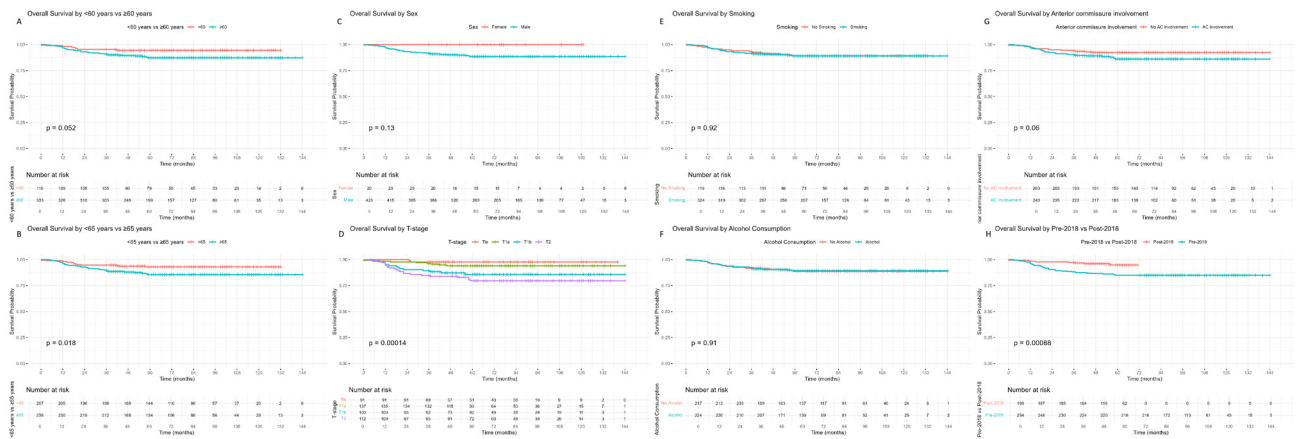


Fig 2. Kaplan-Meier Curves of Overall Survival for 444 Patients with Early-Stage Laryngeal Cancer Treated with Plasma Surgery, Stratified by Various Factors. (A) age, ≥ 60 and < 60 , (B) age, ≥ 65 and < 65 , (C) sex, (D) T-stage, (E) smoking history, (F) Alcohol consumption, (G) anterior commissure involvement, (H) Surgical Period.

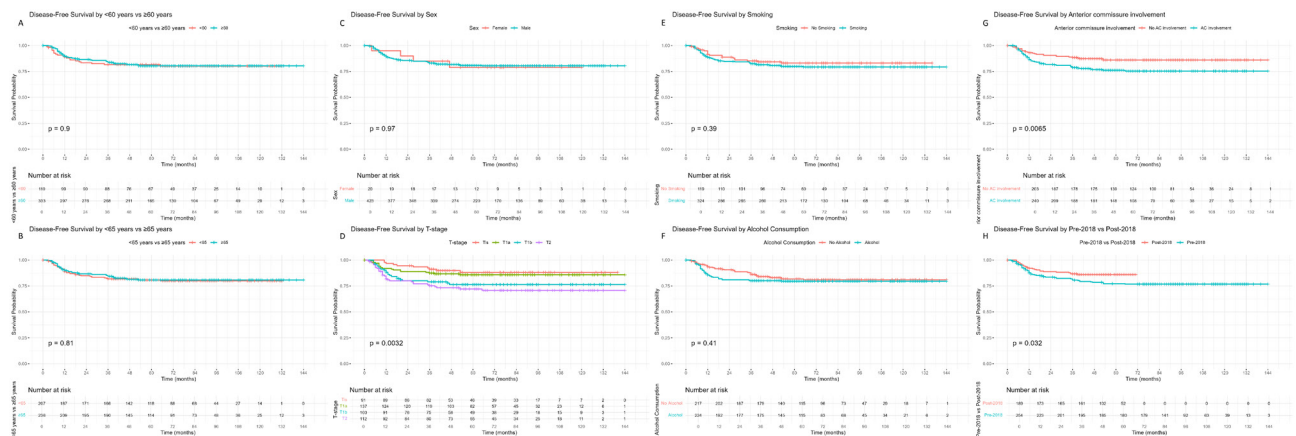


Fig 3. Kaplan-Meier Curves of Disease-free Survival for 444 Patients with Early-Stage Laryngeal Cancer Treated with Plasma Surgery, Stratified by Various Factors. (A) age, ≥ 60 and < 60 , (B) age, ≥ 65 and < 65 , (C) sex, (D) T-stage, (E) smoking history, (F) Alcohol consumption, (G) anterior commissure involvement, (H) Surgical Period.

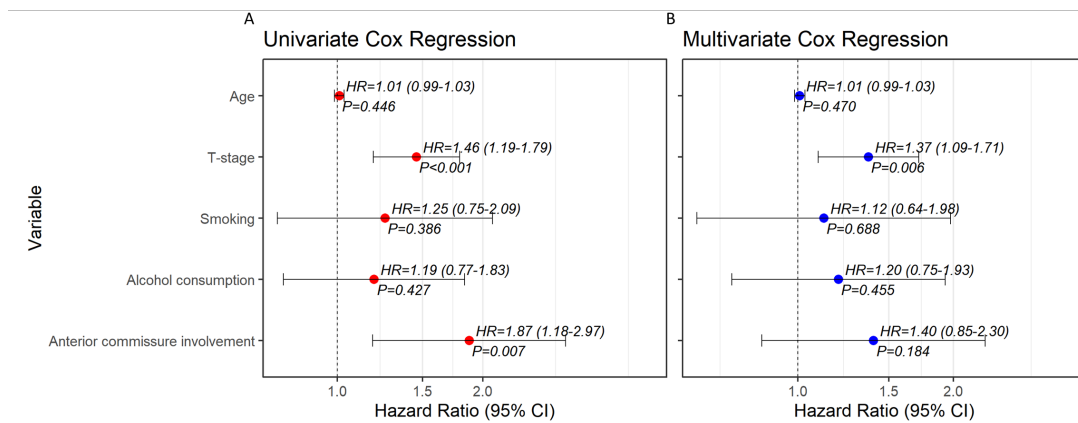


Fig 4. Cox Regression Analysis for Predicting Recurrence in LC Patients. (A) Univariate Cox Regression. (B) Multivariate Cox Regression.

Table 4. Comparison of voice function before and after treatment

	Amplitude perturbation(%)	Fundamental frequency perturbation (%)	Fundamental frequency(Hz)	Harmonic noise ratio(dB)
Before the operation	5.74±0.37	1.44±0.25	144.67±6.82	18.68±3.13
After the operation	2.68±0.41***	1.16±0.14*	137.82±5.43*	23.14±3.95
t	7.314	2.555	2.031	2.889
p	<0.001	0.027	0.049	0.005

Note: * indicates $P<0.05$, and ***indicates $P<0.001$.

Table 5. Comparison of VAS score and vocal cord morphology score before and after treatment

	VAS	Vocal cord morphology
Before the operation	6.16±1.03	2.78±0.10
After the operation	2.07±0.15***	1.14±0.12***
t	24.852	66.402
p	<0.001	<0.001

Note: ***indicates $P<0.001$.