European Archives of Oto-Rhino-Laryngology (2024) 281:3051–3060
https://doi.org/10.1007/s00405-024-08596-y

LARYNGOLOGY

Isoprognostic functional CT map for open partial horizontal laryngectomy

Andy Bertolin[1] · Chiara Varago[1] · Michelangelo Salemi[2] · Gianluca Piccoli[3] · Piero Nicolai[4] · Marco Lionello[1]

Received: 10 June 2023 / Accepted: 4 March 2024 / Published online: 30 March 2024

Abstract

Purpose To identify a radiological map of laryngeal subsites whose involvement by the tumor could predict patients' functional outcomes after open partial horizontal laryngectomy (OPHL).

Methods The present retrospective analysis concerned 96 patients with glottic squamous cell carcinoma, who were radiologically staged with contrast-enhanced neck CT scans before undergoing supracricoid or supratracheal laryngectomy. A radiological map of patients' functional risk was developed by considering the distribution of functional outcomes in relation to the laryngeal subsites involved. The functional outcomes considered were: (i) decannulation at discharge; (ii) time to removal of the nasogastric feeding tube (NFT); (iii) postoperative complication rate; and (iv) length of hospital stay.

Results Involvement of the anterior supraglottis was related to a longer need for NFT, and a longer hospital stay ($p = 0.003$, and $p = 0.003$, respectively). Involvement of the posterior glottis negatively affected the time to decannulation, and the likelihood of postoperative complications ($p = 0.000$, and $p = 0.002$, respectively).

Conclusions Anterior glottic small tumors (without significant subglottic and/or supraglottic extension) are related to the best functional outcomes after OPHL, since the suprahyoid epiglottis and both the arytenoids are likely to be spared.

Keywords Open partial horizontal laryngectomy · Functional outcome · Decannulation · Computerized tomography · Map

Introduction

The goals of partial laryngectomy for cancer are oncological control and a complete recovery of laryngeal function. While an abundance of literature deals with preoperative prognostic factors regarding the oncological outcome, little is known about which preoperative factors are able to predict functional recovery. To the best of our knowledge, no preoperative radiological parameters are known to predict functional outcomes after open partial horizontal laryngectomy (OPHL). Identifying such prognostic indicators would help laryngologists to choose the best treatment option for each patient, and enable them to provide appropriate preoperative counselling.

Contrast-enhanced computed tomography (CT) scanning of the neck is currently part of the diagnostic work-up and staging process for patients with laryngeal squamous cell carcinoma (LSCC). It is used primarily for preoperative staging in laryngeal oncology, but other useful information can be obtained from an accurate radiological examination of the larynx.

The primary endpoint of the present study was to identify a radiological map of laryngeal subsites where involvement by the tumor could predict patients' functional outcome after OPHL. Secondary endpoints were to assess the value of other, demographic and surgical parameters for the purpose of predicting functional outcomes.

✉ Marco Lionello
marco.lionello@aulss2.veneto.it

[1] Otolaryngology Unit, Vittorio Veneto Hospital, Vittorio Veneto, Treviso, Italy

[2] Medical Direction, Vittorio Veneto Hospital, Treviso, Italy

[3] Radiology Unit, Policlinico Città di Udine, Udine, Italy

[4] Neuroscience Department, Otolaryngology Section, University of Padova, Padua, Italy

Methods

Patients

All procedures performed on human participants in the present study were approved by our institutional ethical committee, and complied with the ethical standards of the institution and/or national research committee, and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

The present study involved a retrospective analysis of 96 patients with glottic LSCC who had radiological staging with contrast-enhanced neck CT scans before undergoing supracricoid (OPHL type II) or supratracheal laryngectomy (OPHL type III) [1] at our institution from 2010 to 2016. The tracheostomy was closed with gauze from the third postoperative day onwards, depending on patients' respiratory condition. With the help of a trained speech therapist, all patients started with the oral ingestion of water on the sixth postoperative day, and with semisolid and solid foods on the following days, but the nasogastric feeding tube (NFT) was kept in place until their oral intake was satisfactory (> 75%). A percutaneous endoscopic gastrostomy (PEG) was considered in cases of persistent dysphagia. Patients could be discharged without a tracheostomy tube only after their breathing and swallowing had recovered adequately, with no significant aspiration. Failing this, they were discharged with a tracheostomy tube in place, and outpatient reassessments were scheduled at one month. Patients' clinical charts were retrospectively reviewed, considering the time to decannulation, postoperative complications, the length of hospital stay, and the need for a NFT.

Radiological assessment

CT scanning enables the accurate identification of tumor involvement of laryngeal subsites, as well as three-dimensional reconstructions and volumetric assessments. All LSCC patients at our Radiology Department had preoperative contrast-enhanced neck CT. A volumetric axial CT scan was performed with a 64-slice CT scanner (Revolution Evo, GE, Milwaukee, WI) using a slide thickness of 1.25 mm (120 kV, automatic modulating mA). Scout images (anterior and lateral views) were obtained to ascertain the scanning area covered, from the skull base to the mediastinum. Patients were placed supine, with their head in a neutral position, and instructed to remain still and avoid swallowing or coughing. Multiplanar reformatted sagittal and coronal images were then generated with a slide thickness of 0.6 mm, and the axial plane was reconstructed with an orientation parallel to the true vocal cords to better visualize the glottis. All scans were reworked and analyzed by the same experienced radiologist.

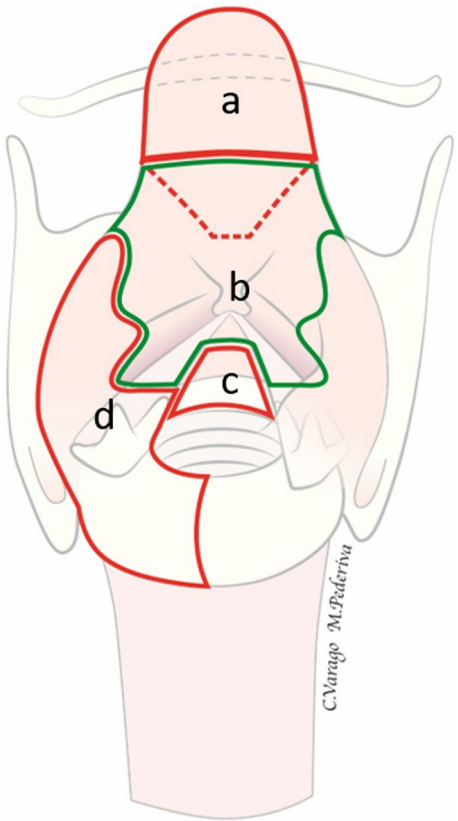

Fig. 1 Functional risk map. Summarizing the concepts explained in this study, we developed a functional risk map that underscores which radiological signs of tumor involvement in the main laryngeal subsites on preoperative CT scans are the most significant for the purposes of predicting functional recovery; anterior supraglottis (**a**), anterior glottis (**b**), anterior subglottis (**c**), and posterior glottis (**d**)

Functional assessment of laryngeal subsites

The findings obtained on radiological staging were used to ascertain which supraglottic, glottic and subglottic sites were most often involved by the tumor, and to classify these subsites according to the impact of their involvement on the choice of surgical technique. Four regions of functional risk were considered: the anterior supraglottis, the glottis, the subglottis, and the posterior glottis (Fig. 1).

- The *anterior supraglottis* consisted of the pre-epiglottic space, and the suprahyoid epiglottis. Involvement of at least one of the subsites in this area prompted complete removal of the epiglottis (OPHL type B in the case of

glottic lesions extending to this region, or OPHL type I in the case of supraglottic lesions) (Fig. 2).

- The *anterior glottis* included the infrahyoid epiglottis, the anterior portion of the false vocal cords, the anterior portion of the true vocal cords, the antero-superior paraglottic space, the anterior commissure, and the thyroid cartilage at anterior commissure level. OPHL type II was performed when the tumor involved this area (Fig. 3).
- The *anterior subglottis* comprised the anterior subglottis, and the cricoid ring. The involvement of this area necessitated the sacrifice of the cricoid ring (OPHL type III) (Fig. 4).
- The *posterior glottis* consisted of the inferior paraglottic space and thyrocrico-arytenoid space (TCAS), the posterior portion of the false vocal cord, the posterior portion of the true vocal cord, the posterior portion of the aryepiglottic fold, the arytenoid, and the cricoid plate. Tumors involving this area prompted the removal of the ipsilateral arytenoid or the crico-arytenoid unit (OPHL type II or type III, respectively) (Fig. 5).

A vertical plane tangent to the vocal process of the arytenoid, and perpendicular to the ipsilateral thyroid lamina was considered as the boundary between the anterior and posterior glottis [2].

Statistical analysis

Correlations between patients' demographic, surgical and cephalometric parameters and their functional outcomes were assessed using univariate (Fisher's exact test) and multivariate (logistic regression) analyses. The functional outcomes considered were: (i) decannulation at discharge (0/1); (ii) time to removal of the NFT (cut-off = 10 days); (iii) postoperative complications (0/1); and (iv) length of hospital stay (cut-off = 2 weeks). Median values were adopted as cut-offs. A $p < 0.05$ was considered significant. The STATA™ statistical package (Stata Corp, College Station, TX, USA) was used for all analyses.

Table 2 Distribution of laryngeal sites involvement according to clinical T stage. (more than one laryngeal subsite could be involved in the same patient)

cT	*n*. cases	Anterior supraglottis	Anterior glottis	Anterior subglottis	Posterior glottis
1a	7	0	7	0	0
1b	6	0	6	0	0
2	33	2	31	7	14
3	40	6	40	12	29
4a	10	2	10	8	17
TOT	96	10	94	27	60

Results

Patients and surgery

Ninety-six patients (88 males and 8 females; age range 28–80 years, median 62 years) were submitted to OPHL for LSCC. Seventy-two patients (75%) underwent supracricoid laryngectomy (OPHL type II) for cT1a disease in 6 cases, cT1b in 6, cT2 in 29, cT3 in 28 and cT4a in 3 cases, respectively. Twenty-four patients (25%) had supratracheal laryngectomy (OPHL type III) for cT1a disease in 1 case, cT2 in 3, cT3 in 12 cases, and cT4a in 8 cases, respectively. Twenty-four patients (25%) were discharged with a tracheostomy cannula due to persistent dyspnea or dysphagia, while 72 were decannulated after 7.2 ± 3.6 days (median 7 days). The time to NFT removal ranged from 6 to 35 days (9.9 ± 4.0, median 9 days). A PEG was performed in 1 patient due to persistent dysphagia after an OPHL type III. Thirty-three patients (34%) experienced at least 1 postoperative complication. The length of hospital stay ranged from 9 to 41 days (14.5 ± 4.8, median 13 days). Table 1 shows

Table 1 Univariate analysis: distribution of functional outcomes by type of surgery

	Tracheostomy cannula at discharge	*P*	Hospital stay > 14 days	*P*	NFT > 10 days	*p*	Postoperative complications	*p*
OPHL (III vs II)	54.2% vs 15.3%	0.000	54.2% vs 31.9%	0.045*	50.0% vs 33.3%	0.154	66.7% vs 23.6%	0.000
OPHL (B vs A)	28.6% vs 24.7%	1.000	85.7% vs 33.7%	0.011	85.7% vs 33.7%	0.011	14.3% vs 35.0%	0.416
OPHL (+1 ary vs no ary)	13.3% vs 27.2%	0.343	60.0% vs 33.3%	0.049*	46.7% vs 35.8%	0.563	35.8% vs 26.7%	0.568

NFT nasogastric feeding tube, *OPHL* open partial horizontal laryngectomy, *OPHL type A* with preservation of the suprahyoid epiglottis, *OPHL type B* without preservation of the suprahyoid epiglottis, *+1 ary* with sacrifice of 1 arytenoid cartilage, *no ary* no sacrifice of arytenoid cartilages

P: Fisher's exact test *p* value (*: one-sided)

Table 3 Distributions of oncological outcomes according the laryngeal site, the kind of surgery and the adjuvant treatment

	Anterior supraglottis (%)	Anterior glottis (%)	Anterior subglottis (%)	Posterior glottis (%)
5y OS	83	84	79	77
5y DSS	85	92	83	72
	OPHL II (%)	OPHL III (%)	Adjuvant treatment (%)	No adjuvant treatment (%)
5y OS	85	84	72	87
5y DSS	89	77	83	90

Table 4 Univariate analysis: distribution of functional outcomes by radiologically assessed laryngeal subsites invaded by the tumor

	Anterior supraglottis (10 cases) (%)	*P**	Anterior glottis (%)	*P**	Anterior subglottis (%)	*P**	Posterior glottis (%)	*P**
Tracheostomy cannula at discharge	20	0.513	23	0.062	46	0.014	40	0.000
Hospital stay > 14 days	80	0.003	38	0.418	61	0.011	40	0.420
NFT > 10 days	80	0.003	36	0.121	53	0.092	38	0.420
Postoperative complications	40	0.462	34	0.568	61	0.002	45	0.002

*Fisher exact test

the results of the univariate analysis on the distribution of functional outcomes by type of OPHL.

Involvement of laryngeal subsites

Analyzing the laryngeal subsites found involved on preoperative radiological imaging in the cohort of 96 patients as a whole, the tumor invaded the anterior supraglottis in 10 patients, the anterior glottis in 94, the anterior subglottis in 27, and the posterior glottis in 60 (more than one laryngeal subsite could be involved in the same patient). Table 2 shows the distribution of laryngeal sites involvement according to the clinical T stage, Table 3 shows the distributions of oncological outcomes according the laryngeal site, the kind of surgery and the adjuvant treatment, while Table 4 shows the results of the univariate analysis regarding the distribution of functional outcomes according to the areas with radiological evidence of tumor invasions. Involvement of the anterior supraglottis correlated with the need to retain the NFT for longer, and with a longer hospital stay (Fisher exact test, $p = 0.003$, and $p = 0.003$, respectively). Involvement of the posterior glottis had a worse impact on the time to decannulation, and the likelihood of postoperative complications ($p = 0.000$, and $p = 0.002$, respectively).

Discussion

The question of functional outcome plays an increasingly important part in the choice between conservative treatments for intermediate-stage or locally advanced glottic carcinoma.

Radiological imaging has so far been used mainly for preoperative disease staging, but it can also reveal which laryngeal structures are invaded by the tumor, and this information can be key to predicting functional recovery. To the best of our knowledge, the present study is the first to have investigated the value of considering the evidence of tumor invasion of different laryngeal subsites on preoperative CT scans for the purpose of predicting functional outcomes after OPHL.

Apart from the well-known implications for oncological outcomes [2], distinguishing between anterior and posterior glottic lesions is important in surgical decision-making regarding the need to remove the adjacent arytenoid or cricoarytenoid unit, so functional recovery is affected as well. Adopting a radiological classification that separately considers laryngeal subsites, such as the anterior supraglottis, anterior glottis and anterior subglottis, enables us to predict the adjustments most likely be needed intraoperatively, depending on the anterior cranio-caudal extension of the tumor [3].

Anterior neoglottic sphincter

Our univariate analysis showed that tumor involvement of the anterior supraglottis had a statistically significant impact on functional outcome in terms of how long the NFT was needed and length of hospital stay ($p = 0.003$, and $p = 0.003$, respectively). This is because the need to completely remove the epiglottis and pre-epiglottic space means that it takes longer for swallowing function to recover, and this prolongs the need for medical assistance and speech therapy during a patient's hospital stay. Although removal of the epiglottis (OPHL type B) negatively affected the recovery of swallowing function and the length of hospital stay in our cohort ($p = 0.011$, and $p = 0.011$, respectively), it was associated with few postoperative respiratory or feeding complications (such as aspiration pneumonia), and with good functional results (in terms of decannulation at discharge). In other words, rehabilitation took longer in these patients, but they experienced few complications. Resection of the epiglottis damages the integrity of the anterior glottic sphincter, making oral feeding rehabilitation a longer process. The absence of the epiglottis is gradually compensated by the backward movement of the tongue base, with good long-term functional results [4] despite patients' prolonged reliance on a NFT in the immediate postoperative period.

A valid backward movement of the tongue base contributes to the efficiency of the neoglottis. In a recently published paper, our group analyzed the value of cephalometric parameters identified on preoperative radiology in predicting functional outcome after OPHL. Patients with a longer genio-hyoid had a better functional outcome, in terms of time to decannulation and length of hospital stay [5]. This is in line with the findings of Bruno et al. who analyzed pre- and postoperative CT scans obtained in 18 patients undergoing partial laryngectomy with cricohyoidoepiglottopexy. The main anatomical variations identified after surgery were a caudo-cranial shift of the laryngotracheal axis, and a downward shift of the hyoid bone, and the greater the displacement of this last element, the better the patients' functional outcomes [6]. The feasibility of sparing the epiglottis, and the efficacy of the backward movement of the tongue base are therefore important to anterior neoglottic sphincter function, and both of these aspects could be predicted preoperatively from the radiological evidence on a patient's CT scan.

Tumor invasion of the anterior subglottis was found associated with worse functional outcomes (Table 2), and this is because of the high likelihood of the cricoid ring being scarified, and the surgical procedure being switched to a supratracheal laryngectomy (OPHL type III).

Posterior neoglottic sphincter

Analyzing the laryngeal subsites in terms of functional risk, involvement of the posterior glottis was found to have a greater impact on the time to decannulation, and the likelihood of postoperative complications ($p = 0.000$, and $p = 0.002$, respectively). This is because the sacrifice of a crico-arytenoid unit leads to leakage from the posterior glottis. The functional efficacy of the posterior glottis relies on a synergistic action of several muscles (the lateral crico-arytenoid, the posterior crico-arytenoid and, when both arytenoids are preserved, the inter-arytenoid muscles), involving a multiplanar movement of the arytenoid forwards, downwards and internally that causes the backward movement of the tongue base and closure of the neoglottis to protect the lower airways [7]. A functional compensation is gradually achieved by the contralateral crico-arytenoid unit, but this takes time.

In the literature, sclerosis of the arytenoid has repeatedly been mentioned as a sign of the tumor's proximity to the cartilage, and in some cases, this prompted removal of the cartilage to ensure oncological radicality [8]. While this information can contribute to the preoperative work-up, it has proved to be more specific, but less sensitive than preoperative endoscopic evidence of arytenoid motility [8–10]. This is because cartilage sclerosis is not per se an indicator for arytenoid resection. In the present cohort, involvement of the whole ipsilateral posterior glottis was found to have a significant impact on both oncological and functional outcomes. This finding is consistent with various reports regarding the importance of this laryngeal subsite in terms of oncological results [2, 11]. Tumors spreading posteriorly also prompt a switch from supracricoid (OPHL type II) to supratracheal (OPHL type III) laryngectomy, due much more to the involvement of the crico-arytenoid joint than to the cranio-caudal extension of the tumor. Posterior lesions are therefore more likely to be managed with OPHL type III. The results of the present study confirmed that patients' functional outcomes are worse after OPHL type III than after OPHL type II, in terms of decannulation at discharge, length of hospital stay, and postoperative complications ($p = 0.000$, $p = 0.045$, $p = 0.000$, respectively). In terms of the length of hospital stay ($p = 0.049$), the functional outcome was

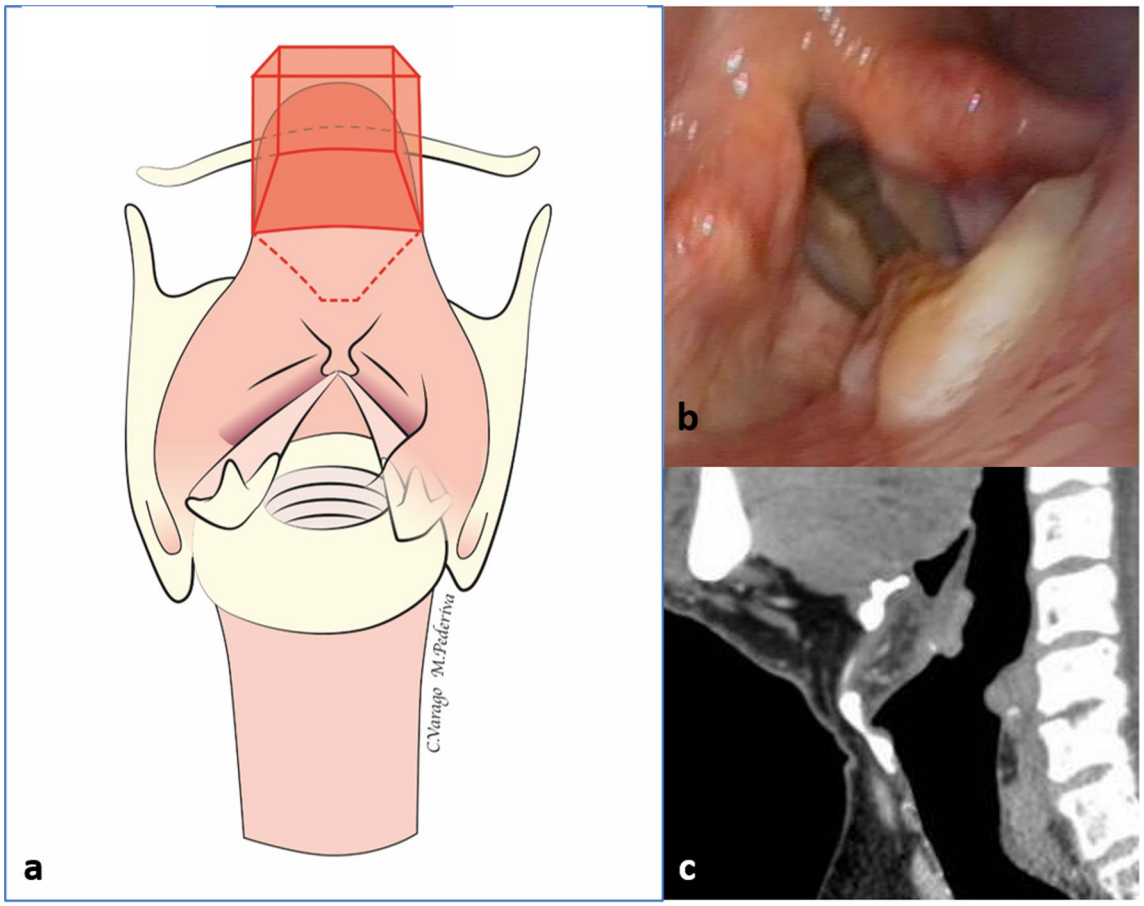

Fig. 2 Anterior supraglottis: **a** diagram; **b** endoscopic view showing supraglottic tumor involving the laryngeal aspect of the epiglottis, with normal vocal cord motility; **c** contrast-enhanced CT scan

likewise worse in cases where one of the arytenoid cartilages was removed, by comparison with those in which both arytenoids were spared.

The strengths of the present study are the large number and homogeneity of the population under examination, since all patients underwent radiological imaging, surgery and postoperative rehabilitation by the same team of radiologists and surgeons belonging to the same institution. On the other hand, the weaknesses consist in the mono-institutional setting, the lack of a prospective study design and of a control group. Further studies, preferably multicentric, with larger patients number and structured in a prospective and case–control manner, are needed to confirm our results' validity.

Conclusions

The best functional outcomes after OPHL are achieved for small anterior glottic tumors (with no significant subglottic or supraglottic extension). This is because the suprahyoid epiglottis and both the arytenoids are likely to be spared.

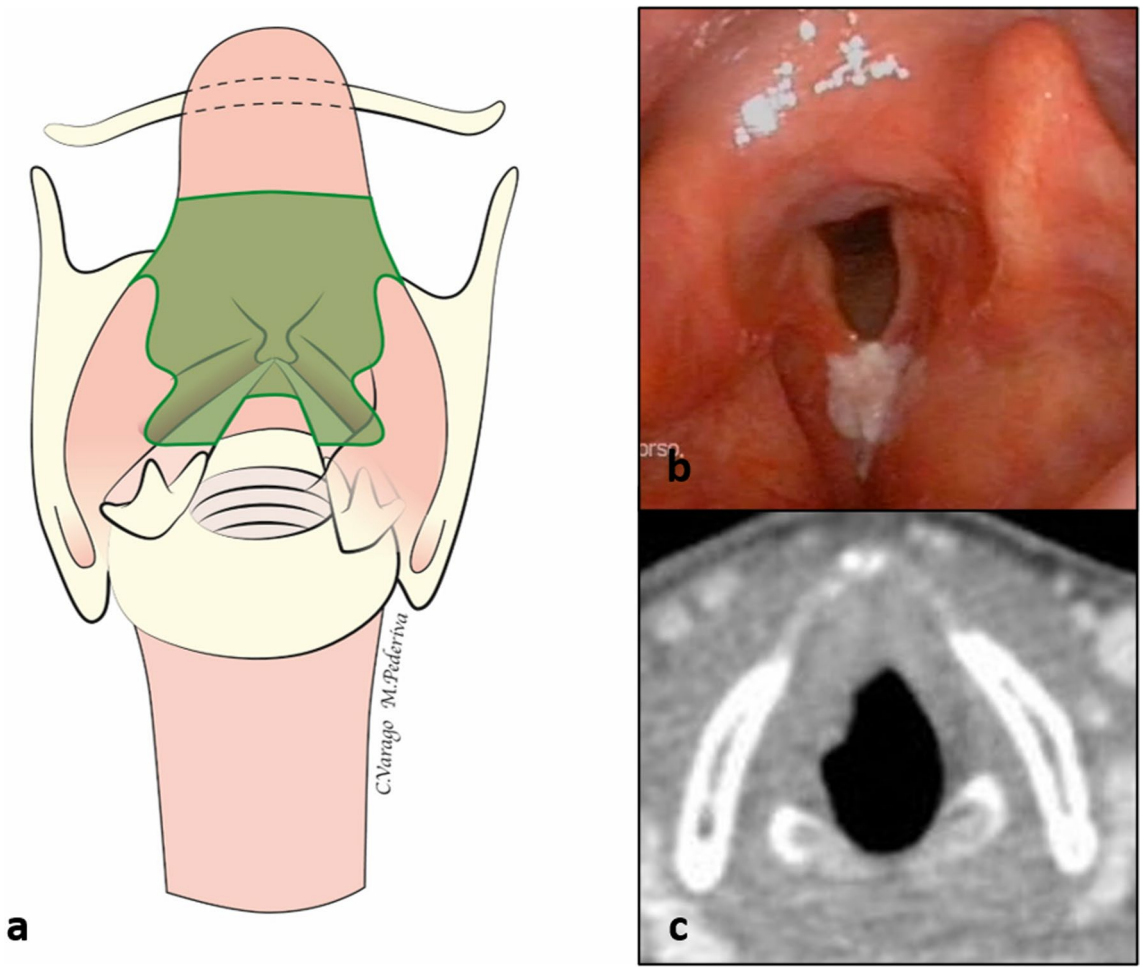

Fig. 3 Anterior glottis: **a** diagram; **b** endoscopic view showing anterior glottic tumor, with bilateral vocal cord motility impairment, and normal arytenoid motility; **c** contrast-enhanced CT scan

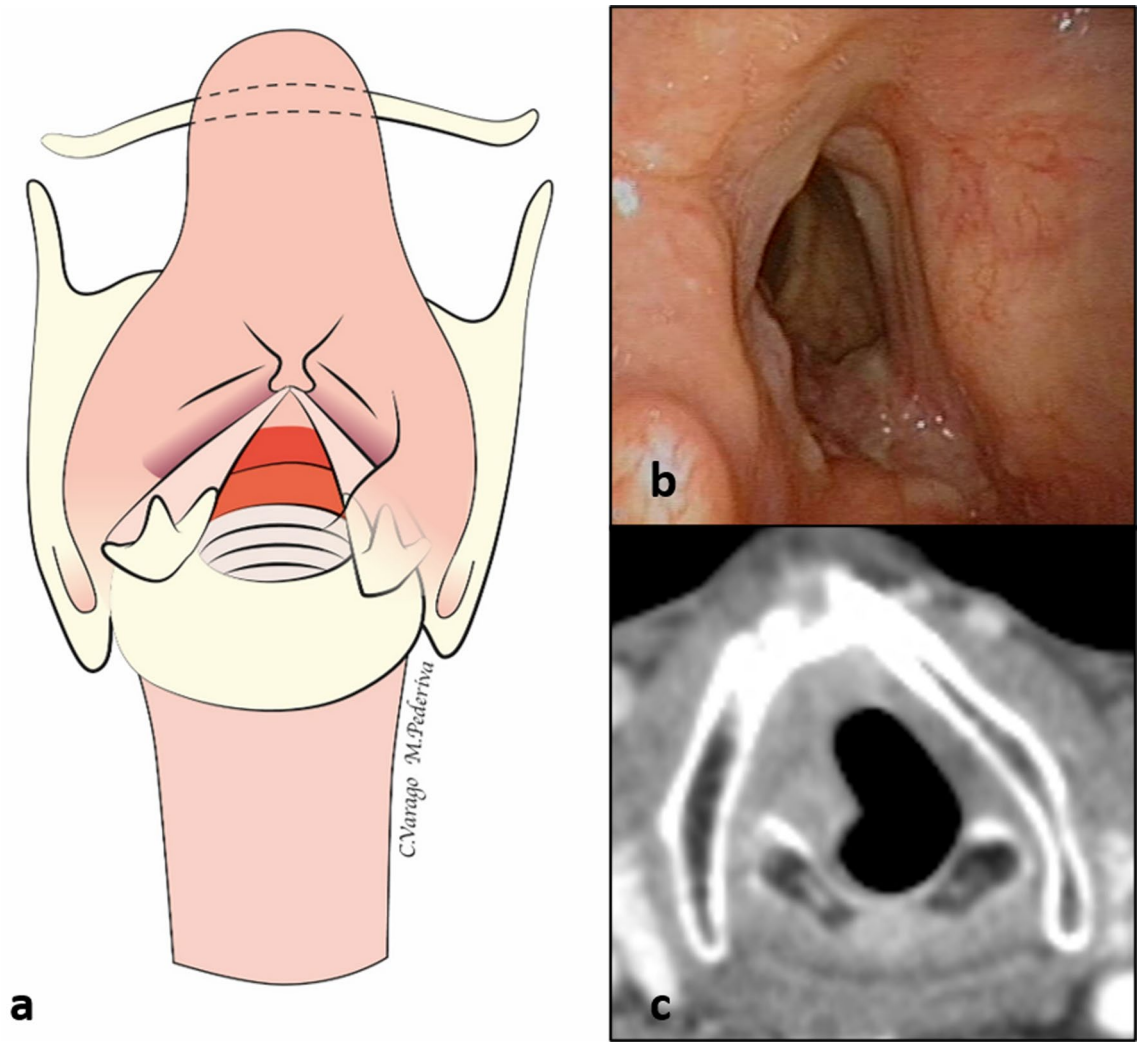

Fig. 4 Anterior subglottis: **a** diagram; **b** endoscopic view showing anterior glottic-subglottic tumor, with right vocal cord motility impairment, and normal arytenoid motility; **c** contrast-enhanced CT scan

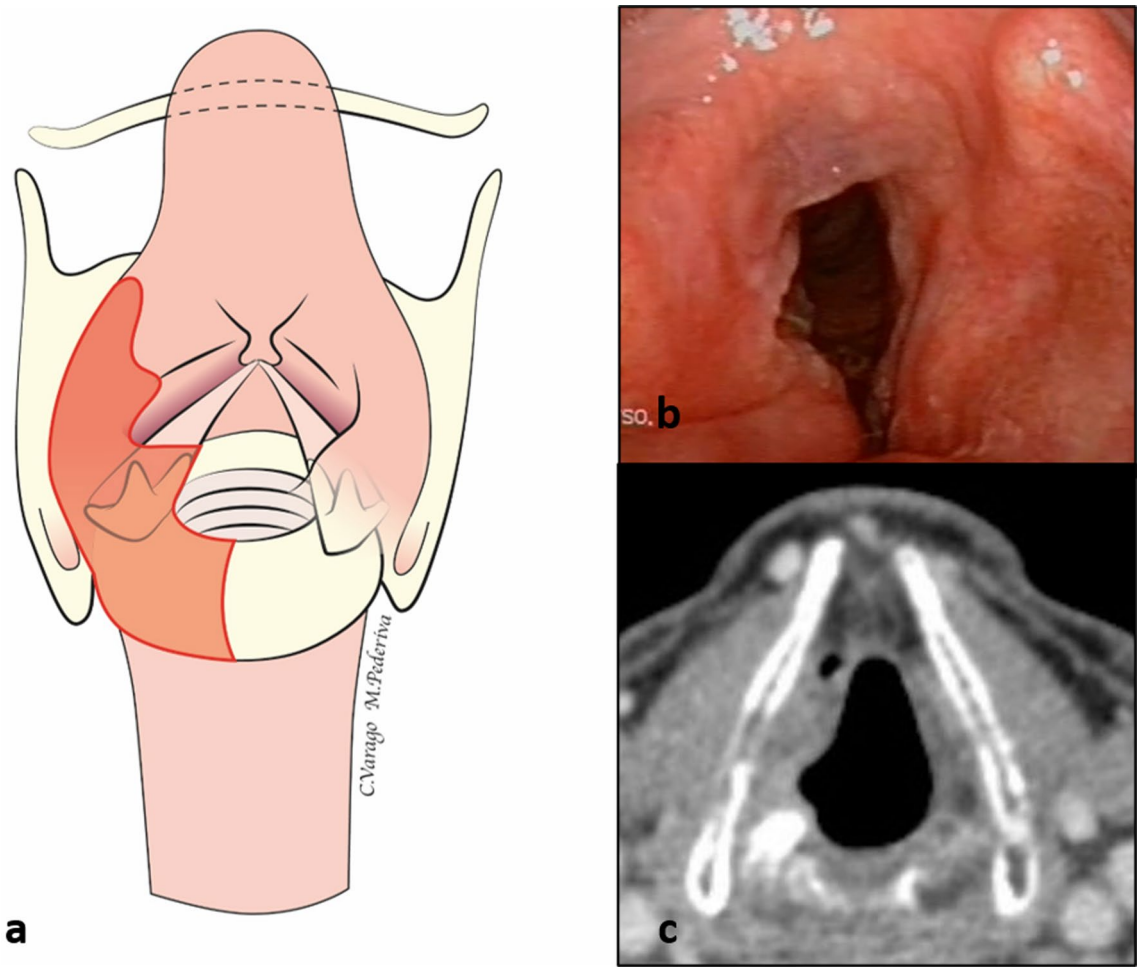

Fig. 5 Posterior glottis: **a** diagram; **b** endoscopic view showing posterior transglottic tumor, extending into the subglottis, with fixed right vocal cord and arytenoid; **c** contrast-enhanced CT scan

Acknowledgements The authors thank Frances Coburn for correcting the English version of this paper. They also thank all the medical and paramedical staff at the Otolaryngology Unit—Vittorio Veneto Hospital, for collecting the follow-up data, and the Association "Amici della voce" (Friends of the Voice) for its support in preparing the manuscript.

Funding This study was supported by a personal grant.

Data availability Not available.

Declarations

Conflict of interest There is no conflict of interest.

Ethics approval All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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