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RESEARCH

TLM, TORS and RT in early supraglottic SCC: a meta-analysis of oncological and functional outcomes

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Abstract

Management of early stage supraglottic squamous cell carcinoma (SCC) evolved with the advent of transoral surgical and new radiation techniques. Current guidelines recommend a single therapeutic modality treatment (either organ-sparing surgery or definitive radiotherapy) yet the optimal approach remains controversial. We conducted a systematic review and meta-analysis to compare long-term (five years) oncological and functional outcomes in early SCC. Two independent reviewers screened the literature available on Pubmed, Embase and Google Scholar (1990–2025). Eligible studies included patients with early SCC (T1-T2/N0-N1/M0), treated with transoral laser microsurgery (TLM), transoral robotic surgery (TORS) or Radiotherapy (RT). A systematic review with comprehensive meta-analysis were performed using R© software. 59 studies were included: 19 RT; 30 TLM, 6 TORS and four on mixed treatment studies. Five-year overall survival favored surgical approaches, particularly TORS, with rates of 78% for TORS, 72% for TLM compared with 55% for RT. Swallowing outcomes and Quality-of-Life (QoL) assessments were heterogeneous and not directly comparable. Available functional data (tracheostomy, gastrostomy and total laryngectomy rates) showed similar results across techniques. Meta-regression analyses adjusting for tumor stage, treatment period and use of adjuvant RT confirmed these findings. TORS and TLM appear to be associated with improved overall survival and comparable functional results compared with 2D/3D RT. Further comparisons of modern (intensity modulated) RT and TORS are needed, based on more robust studies including a larger number of patients. QoL and swallowing data remain limited and heterogeneous, highlighting the need for prospective studies using validated assessment tools, comorbidity analysis and multiple treatment arms.

Keywords Early supraglottic squamous cell carcinoma · Transoral robotic surgery · Transoral laser microsurgery · Intensity modulated radiotherapy

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Introduction

Laryngeal cancer represents one-third of all head and neck cancers with 12,650 new cases every year in USA [1]. About 35% are supraglottic, which have worse prognosis compared to glottic cancers [2, 3]. This is largely due to minimal symptomatology and richer lymphatic drainage, such that up to 40% of supraglottic tumors present at an advanced loco-regional stage at time of diagnosis [4, 5].

In recent decades, therapeutic options have evolved. In surgery, minimally invasive transoral approaches have emerged in the form of Transoral Laser Microsurgery (TLM) since 90's [6–9] and Trans-Oral Robotic Surgery (TORS) since 2007 [10–12]. These offered better functional outcomes without the use of systematic tracheostomy compared to open total or partial laryngectomy [13]. In radiotherapy (RT), Intensity Modulated Radiotherapy (IMRT) techniques were developed in the 1990s' allowing better organ-preservation than 2D and 3D conformal techniques with reduced xerostomia and dysphagia [14–19]. For early stage supraglottic cancers (T1-T2/N0-N1), National Comprehensive Cancer Network (NCCN) guidelines recommend a single modality treatment, either organ-sparing surgery or definitive RT [20–24]. The optimal treatment remains controversial. No prospective comparative head-to-head study has been performed, and the majority of the literature is limited to small single institution retrospective studies. One multicentric prospective study on TLM is interesting about the functional results but without comparison with TORS or IMRT [25].

Different systematic reviews have been performed. None has included all three treatment strategies or has examined oncological and functional outcomes with a short- and long-term perspective (five years) [13, 26–35]. The aim of the study was to conduct a contemporary systematic review on treatment outcomes for early supraglottic SCC treated with TORS, TLM and definitive RT.

Materials and methods

This study was conducted according to the PRISMA statement guidelines [36]. A protocol was written and registered on Prospero (CRD42022367444) prior to data collection [37].

Literature research strategy

A comprehensive search was carried out in PubMed, Embase and Google Scholar between January 1990 and November 2025 to compare TLM, TORS and RT. The final search was performed on November 3, 2025. Keywords used for population identification included: "squamous cell carcinoma" AND "laryngeal" or "supraglottis" or "supraglottic". Keywords used for treatment included: "TORS" or "Transoral robotic surgery","robotics", "robot"; "IMRT" or "Radiotherapy" and "TLM", "Transoral laser microsurgery", "laser therapy" or "microlaryngoscopic laser surgery". (See full search algorithm in Appendix 1).

Inclusion criteria

Articles eligible for inclusion had the following criteria: early supraglottic SCC (including T1-T2/N0-N1/M0 [38]) treated by TLM, TORS or RT; retrospective or prospective cohort studies; a minimum of 10 cases; controlled or uncontrolled, randomized or not; published in peer-reviewed journals. Languages accepted were English, French or Dutch.

Exclusion criteria

Narrative reviews, cadaveric or animal studies, and operative technique reports were excluded. Articles studying multiple different head and neck cancer sites, where specific raw data on supraglottic SCC tumors could not be extracted, were also excluded.

Study selection

Titles and abstracts were screened by two independent reviewers (HS and BK) for eligibility using Endnote X9 (Clarivate Analytics, PA, USA). Full texts were used to confirm the final inclusion. In cases of disagreements, a third expert (SV, JFD or RC) determined inclusion.

In cases of study duplication with population overlap, the most recent or complete study was selected for inclusion. In papers where multiple tumor sites were included corresponding authors were contacted to obtain disaggregated data. After two unsuccessful attempts within four weeks, papers were excluded.

Data extraction

Data were extracted by one reviewer (SH) and confirmed by a second (BK). Discrepancies were reviewed, discussed and arbitrated by a senior author. Missing data were addressed by contacting the corresponding authors. The reason for missing data was reported.

If a study included patients with early and advanced supraglottic tumors, only early (T1-T2/N0-N1) patients were included. Therefore, the number of patients for specific studies included in this meta-analysis may be different than original study populations.

The extracted data included: first author name, publication year, country of origin, study design, sample size, treatment type, patient demographics (mean age, gender, comorbidities), tumor characteristics (T and N stage and subsite), adjuvant treatment, unilateral or bilateral neck dissection and margin status.

Main outcomes measurement

Oncological outcomes examined were overall survival rates (OS), disease specific survival rates (DSS), Disease-free survival rate (DFS), local and regional relapse rates (LR and RR), distant metastasis rate (DR), proportion of patients with adjuvant radiotherapy and follow-up (FU) duration. *Functional data* extracted were proportion of patients with tracheostomy, gastrostomy, laryngectomy and aspiration, adverse events, QoL questionnaire or scale (e.g. MDADI, EORTC QLQ-C30, EORTC H&N35 or H&N43, VHI) [39–43]. Timepoints were one, two and five year rates.

Bias/quality assessment

The Newcastle-Ottawa quality assessment scale (NOS) was used to determine the overall quality and bias risk of included cohort studies by two independent reviewers (SH and BK) [44] (Appendix 2).

Statistical analysis

All analyses were done in R 4.5.2 with the *meta* and *metafor* package using the following functions: *metaprop*, *metareg*, *forest and funnel*. When available, the number of event (***n***) and the size of the cohort (***n***) were extracted from the study. For oncological outcomes, the number of events (***n***) was derived from the Kaplan-Meier estimate of the survival function at five-years. When the five-years survival function was not available (this concerns 7% of the overall survival estimations), we used the following formula to infer the five-years survival function from another timepoint () based on the hypothesis of an exponential distribution of events:

$$n_{events} = (1 - e^{\frac{\ln(S_t)}{T} * 60}) * n_{total}$$

Where possible, meta-analysis of proportion was performed. This meta-analysis relied on inverse variance method and applied a logit transformation to the proportions. A continuity correction with an increment of 0.5 was used when at least one study has a zero-cell count.

To control the potential influence of confounders and to compute adjusted odds ratios (OR) or probability of event, the meta-regression model included the following covariates: study period (ending before or after 2008), the proportion of stage II and III patients and proportion of patients with adjuvant RT (0% when intervention is RT). A funnel plot analysis was performed to identify publication bias.

Results

Studies selection and bias assessment

12.561 studies were identified according to the search criteria. After screening, we retrieved 63 full articles. Eleven duplicate studies were excluded. A systematic review of all references and previous systematic reviews yielded seven additional studies, leaving 59 studies for final analysis (Fig. 1).

Study design and patient demographics

Of the 59 studies included, 19 examined outcomes after RT, 30 TLM and six TORS; two compared RT and TLM [45, 46], one TORS and TLM [47] and one compared all the three techniques [48].

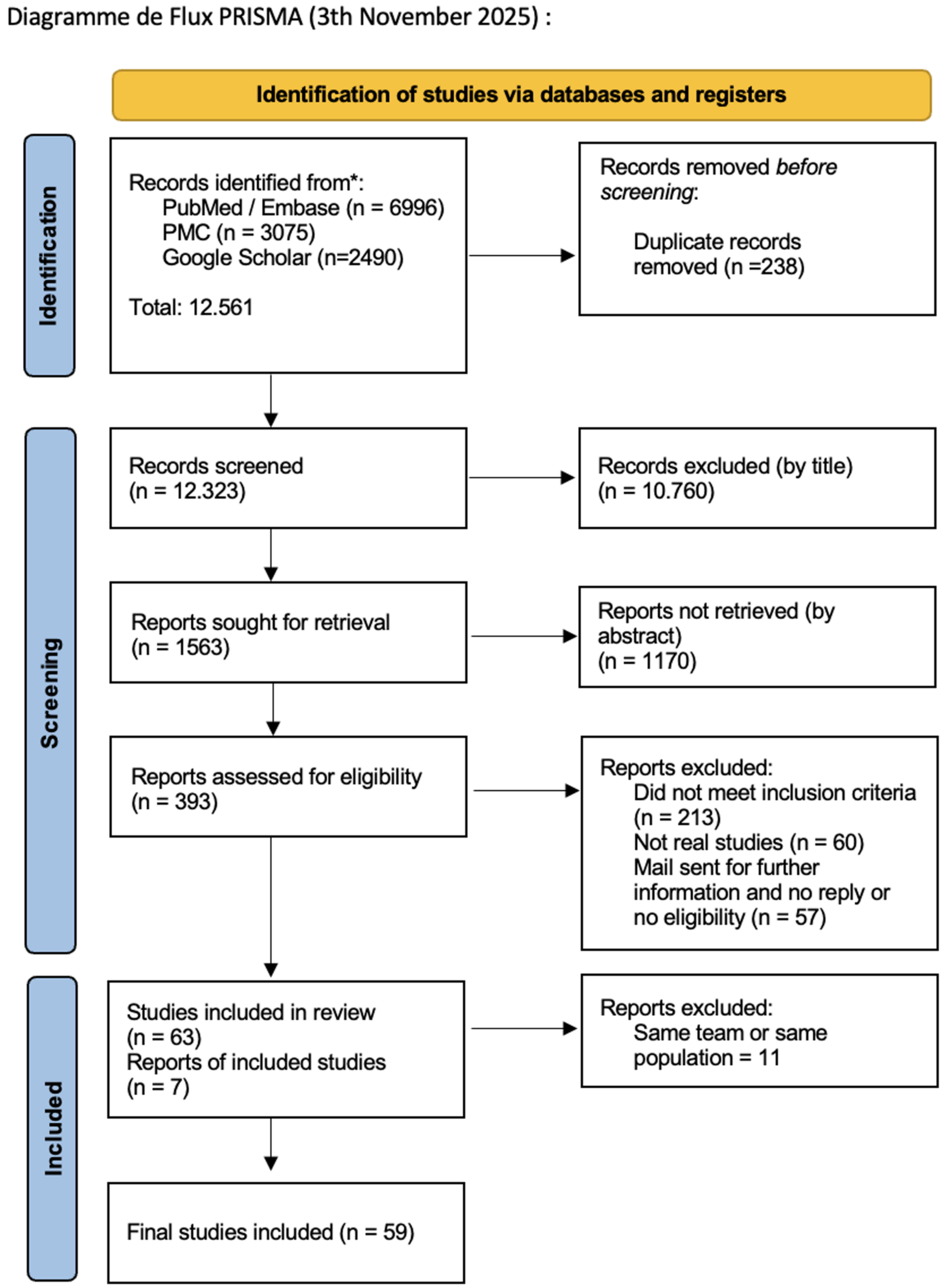
Regarding RT studies, only two studies examined IMRT outcomes [49, 50]. For more consistency, we classified them into three groups: (1) 2D/3D techniques before 2008, (2) studies with both 2D/3D and IMRT techniques around 2008 and in which techniques used were unclear, and (3) studies after 2008 when IMRT became more common.

Table 1 summarizes the main demographic data. Fifty-one of 59 studies were retrospective cohort studies and 35 covered single treatment arms. Six studies compared TLM to open surgery (total/partial laryngectomy). Seven studies examined national databases [45–48, 51–53]. Stages were defined according to the AJCC 8th Edition [38]. The median age was comparable between treatment arms (62 for TORS, 61.9 for TLM and 63.5 years for RT). The overall stage was similar between treatment groups (42.9% of stage I in the TORS group, 39.2% for TLM, and 43.2% for RT). There were slightly more stage III patients in the TORS group (10.6%, versus 7% for TLM and only 1.2% for RT). Comorbidity data were rarely reported and were highly heterogeneous limiting comparison: five studies presented them as binary variables (present/absent), two used the American Society of Anesthesiology (ASA) score, two the Eastern Cooperative Oncology Group (ECOG) score, and only three reported the Charlson Comorbidity Index [46, 48, 54, 55].

Oncological results

Figure 2 presents the OS results; five-year OS favored the surgical group with survival of 78% for TORS (72–83%)

Fig. 1 PRISMA Flow Chart



and 72% for TLM (67–77%) compared to 55% for RT (51–59%) with a $p \leq 0.01$.

Five-year DSS was 90% for TORS, 84% for TLM and 73% for RT with a non-significant statistically difference (Appendix 4, Fig. 1). Local recurrence showed a trend toward improvement in the surgical groups, while regional recurrences were comparable across groups. Distant recurrence appeared higher in the TORS group; however, this finding was driven by a single study in which four of 29 patients developed metastases (Fig. 2 and Appendix 4, Fig. 2–4).

Functional results

Regarding functional results, data type was highly variable. Three outcomes were in 39 out of 59 studies described: the presence of tracheostomy, functional laryngectomies and permanent gastrostomy. However, there was no statistical differences between the groups with a proportion around 1–5% for each outcomes (Table 2 and Appendix 5, Figs. 1, 2 and 3).

Dabas et al. including prophylactic tracheostomy in 6.6% and gastrostomy in 13.3% of cases [56]; however, it was

Table 1 Demographic information of included studies

Authors (year)	Inclusion Years	Patients Mean age (years)	Tumors Stages (*N*)			Median Follow-up duration (months)
			I	II	III	
1/ Radiotherapy (2D/3D)						
Before 2008:						
Arshad 2014*	1988–2008	63	1043	1235	0	63 †
Cano 1993	1972–1989	65	15	27	2	15 †
Carl 1996	1972–1990	65	27	0	0	-
Jones 2004	1964–2003	63	90		0	199
Megwalu 2016*	1992–2009	64	964		0	-
Hinerman 2002	1964–1998	-	17	74	79*	24 †
Nakfoor 1996	1981–1992	-	21	58	11	56
Orus 2000	1984–1996	64	27	63	0	29
Rutkowski 2011	1994–2004	61	0	61	12	100
Spriano 1997	1983–1992	62	32	59	0	80
Sykes 2000	1982–1992	63	65	136	0	66
Santos 1998	1965–1990	56	3	6	10*	44 †
Waersted 2021						
(2D/3D Arm)	2000–2007	63	28	33	0	89
(**IMRT** Arm)	2008–2014	63	29	32	0	89
Between 2008						
Buglione 2015	1984–2012	-	56	86	0	65
Blomkvist 2023*	2000–2014	68	11 (T1)	42 (T2)	0	-
de Carvalho 2021	1995–2014	61	37		0	55
Lee 2020*	2004–2015	67	2055	1166	0	-
Rao 2017	1987–2012	59	18		0	81
Oridate 2009	2006–2007	76	0	11	0	38
After 2008						
Al-Qurashi 2021*	2010–2016	64	1066	2021	0	39
Panuganti 2022*	2010–2016	65	0	991	0	42 †
Rutkowski 2014 (**IMRT**)	2002–2010	60	0	83	12	59
2/ TLM:						
Before 2008						
Agrawal 2007 ‡	1997–2001	64	24		10	69 †
Ambrosch 1998	1986–1994	61	12	36	0	55 †
Bernal-Sprekelsen 04 ‡	1994–2002	61	16 (T1)	41 (T2)	0 (T3)	-
Bussu 2009	1996–2005	61	11	30	2	60 †
Canis 2012	1980–2006	59	24	75	11	66
Csanady 2011	1987–2006	55	36	12	7	-
Davis 2004 ‡	1987–1999	61	0	30	7	66 †
Dyckhoff 2021	1998–2004	60	31 (T1)	39 (T2)	0 (T3)	100
Eckel 1997 ‡	1986–1992	55	9	28	6	62
Grant 2007 ‡	1997–2005	63	6	8	5	31 †
Iro 1998	1979–1993	60	33	36	11	37
Karatzanis 2009	1970–2004	60	19	30	0	67 †
Motta 2003	1981–1998	59	45	61	18*	60 †
Prgomet 2002	NA	57	5	9	5	-
Remacle 2008	1992–2004	62	11	27	6*	44
Rudert 1999	1981–1994	62	2	7	5	24 †
Thumfart 1995	1986–1992	-	24*			37 †
Between 2008:						
Ambrosch 2018	2002–2012	62	8	22	26*	47 †
Breda 2014	2000–2011	62	13	10	0	41 †
Gonzalez-Marquez 12	1999–2009	60	8	11	17*	49
Medina 2012	1999–2011	64	11 (T1)	21 (T2)	7 (T3)	47 †
Megwalu 2016*	1992–2009	64	190		0	-
Predegal 2018	1998–2013	63	-	-	-	24 †

Table 1 (continued)

Authors (year)	Inclusion Years	Patients Mean age (years)	Tumors Stages (*N*)			Median Follow-up duration (months)
			I	II	III	
Piazza 2016	1988–2013	65	28	38	20*	61 †
To 2015	2000–2013	65	2	8	0	33
After 2008:						
Ambrosch 2024 ‡	2015–2018	62	1	45	23*	24
Al-Qurausshi 2021*	2010–2016	64	51	32	0	39
Carta 2018	2010–2017	62	11	17	7	41 †
Hussain 2020	2007–2017	65	17	20	7*	24 †
Panuganti 2022*	2010–2016	63	0	76	0	59 †
Papazian 2023*	2010–2019	64	253 (T1)	171 (T2)	0 (T3)	58
Saraniti 2022	2010–2020	61	7	3	0	-
Sofi 2024	2013–2016	55	5 (T1)	19 (T2)	0	74 †
Vilaseca 2022	1998–2019	64	58	70	110	24 †
3/ TORS:						
After 2008:						
Al-Qurausshi 2021*	2010–2016	64	26	18	0	39
Dabas 2019 ‡	2013–2015	63	22	24	0	41 †
Doazan 2017	2008–2015	61	33	34	17	43 †
Hans 2020	2009–2017	58	23	17	14	24 †
Mendelsohn 2013 ‡	2008–2010	-	3	5	2	28
Muderris 2023	2012–2015	58	14		7*	49 †
Papazian 2023*	2010–2019	62	131 (T1)	140 (T2)	0 (T3)	58
Slama 2015	2011–2014	59	Only T1-T2 / N0-N1			34 †

Authors *Correspond to studies which included National Database analysis. Design study: ‡ = Prospective. Follow-up: † correspond to mean, rest are in Median

Stade III: with * if it includes T3, without * correspond only to T1-T2/N1

not specified whether these procedures were temporary or permanent. In other studies, on TORS outcomes, no tracheostomies or gastrostomies were reported [31, 57, 58]. The aspiration rate was 3% for TORS, 6% for TLM, and 1% for RT, respectively (Appendix 5, Fig. 4). Definitions of aspiration and diagnostic methods among studies varied and were often based on non-standardized or non-objective assessments. Available data did not specify whether aspiration was transient or permanent, and only one study reported aspiration rates after RT (Appendix 5, Fig. 4).

Swallowing and QoL outcomes were inconsistently reported and highly heterogeneous, precluding from meaningful comparison across treatment modalities. Objective swallowing assessments were reported only in a few TLM studies using Fiberoptic Endoscopic Evaluation of Swallowing (FEES)-based scales (e.g., PAS, SPS, Donzelli) [59–61]. RT studies rarely included objective measures. Evaluation was not reported in the TORS subgroup. About the TLM group, 3 articles reported MDADI analyses [25, 62, 63].

Meta-regression

Univariable and multivariable meta-regression analyses adjusting for the proportion of stage II–III patients and treatment period (< or ≥2008) as well as adjuvant radiotherapy yielded results consistent with those observed in the Forest Plot. OS and DSS are still in favor of TORS subgroup (Table 2 and Annex 6).

However, in surgical subgroup receiving adjuvant RT, outcomes were worse, particularly for functional outcomes such as tracheostomy and gastrostomy (OR 3.48 for tracheostomy and even 7.11 for gastrostomy).

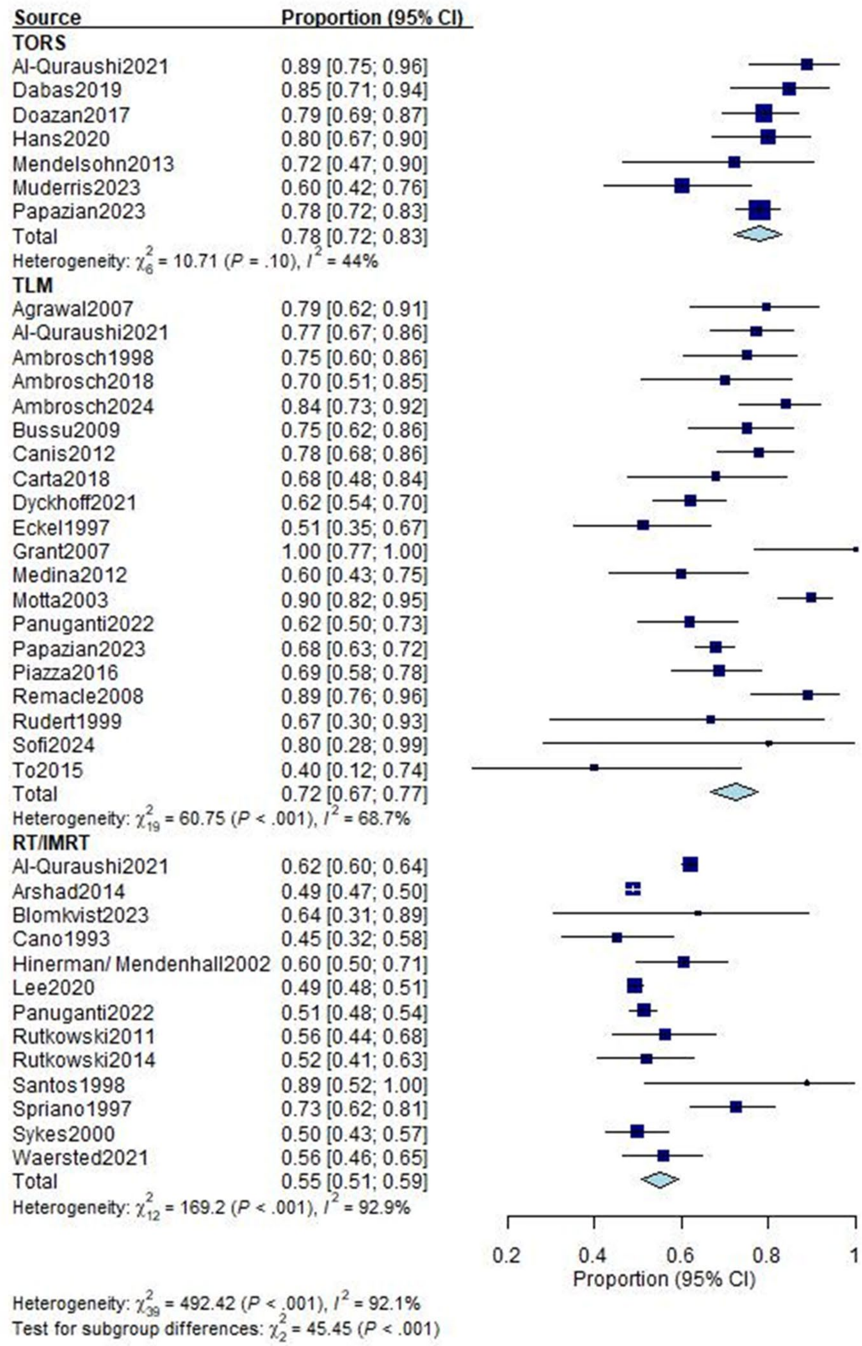
Funnel plots

Funnel plot for OS and DSS suggested possible publication bias, with fewer small negative studies. In contrast, tracheostomy and gastrostomy analyses were more symmetrical with fewer small positive studies.

Discussion

This is the first and only systematic review comparing oncological and functional outcomes of different treatment modalities for early supraglottic SCC. In it, we include 59 studies and found better oncological results for TORS compared to TLM and RT in terms of OS, DSS, and LRR. The functional outcomes were similar between the three techniques. Unfortunately, we were unable to compare

Fig. 2 Forest Plot of 5 years Overall Survival by treatment (TORS, TLM or RT). Resume of all Forest Plot for 5 years Overall Survival (OS), Disease-Specific Survival (DSS), Disease-Free Survival (DFS), Local Recurrence Rate (LR), Regional Recurrence Rate (RR), Distant Recurrence Rate (DR), Tracheostomy, Gastrostomy, Total laryngectomy and Aspiration Rate



	TORS	TLM	RT	p-value
OS	0.78 (0.72-0.83)	0.72 (0.67-0.77)	0.55 (0.51-0.59)	p<0.001
DSS	0.90 (0.65-0.98)	0.84 (0.78-0.89)	0.73 (0.59-0.84)	p= 0.16
DFS	0.88 (0.61-0.97)	0.76 (0.68-0.82)	0.81 (0.76-0.84)	p= 0.38
LR	0.13 (0.09-0.19)	0.12 (0.08-0.16)	0.23 (0.16-0.32)	p= 0.02
RR	0.09 (0.01-0.40)	0.06 (0.03-0.13)	0.07 (0.04-0.14)	p= 0.91
DR	0.22 (0.04-0.68)	0.06 (0.03-0.10)	0.06 (0.04-0.11)	p= 0.36
Tracheostomy	0.03 (0.01-0.10)	0.03 (0.02-0.05)	0.01 (0.01-0.03)	p= 0.20
Gastrostomy	0.04 (0.01-0.16)	0.04 (0.02-0.05)	0.01 (0.00-0.03)	p= 0.10
Total Laryngectomy	0.01 (0.00-0.05)	0.03 (0.02-0.05)	0.01 (0.01-0.03)	p= 0.12
Aspiration	0.03 (0.01-0.08)	0.06 (0.04-0.11)	0.01 (0.00-0.03)	p= 0.03

Table 2 Univariate and multiple meta-regression for OS, DSS, tracheostomy and Gastrostomy. Legend: OS: Overall Survival, DSS: Disease-specific survival, CI confidence Interval

Characteristic	Univariate meta-regression			Multiple meta-regression		
	OR (beta)	95% CI	*p*-value	OR (beta)	95% CI	*p*-value
OS						
TLM	0.74	0.50, 1.10	0.14	0.60	0.39, 0.92	0.019
RT/IMRT	0.35	0.24, 0.52	<0.001	0.22	0.13, 0.37	<0.001
year≥2008	0.79	0.54, 1.15	0.2	0.73	0.55, 0.97	0.031
Stages II/III	0.68	0.38, 1.21	0.2	0.76	0.50, 1.16	0.2
RT adjuvante	2.31	1.08, 4.95	0.031	0.47	0.20, 1.07	0.072
DSS						
TLM	0.67	0.22, 1.99	0.5	0.34	0.10, 1.20	0.10
RT/IMRT	0.31	0.10, 0.92	0.034	0.10	0.02, 0.52	0.006
year≥2008	1.06	0.57, 1.97	0.8	0.76	0.42, 1.36	0.4
Stages II/III	0.65	0.27, 1.59	0.3	0.58	0.24, 1.37	0.2
RT adjuvante	2.18	0.58, 8.20	0.2	0.25	0.03, 2.14	0.2
Tracheostomy						
TLM	0.73	0.24, 2.24	0.6	0.72	0.12, 4.19	0.7
RT/IMRT	0.28	0.07, 1.14	0.075	0.26	0.02, 3.73	0.3
year≥2008	1.16	0.49, 2.75	0.7	0.63	0.20, 1.98	0.4
Stages II/III	0.60	0.10, 3.65	0.6	1.32	0.08, 20.9	0.8
RT adjuvante	3.48	0.63, 19.3	0.2	1.62	0.13, 19.7	0.7
Gastrostomy						
TLM	0.47	0.17, 1.33	0.2	0.79	0.15, 4.08	0.8
RT/IMRT	0.14	0.03, 0.56	0.005	0.39	0.03, 4.73	0.5
year≥2008	1.73	0.71, 4.19	0.2	1.03	0.32, 3.28	>0.9
Stages II/III	0.56	0.08, 4.06	0.6	0.62	0.05, 7.29	0.7
RT adjuvante	7.11	1.73, 29.2	0.007	4.58	0.65, 32.2	0.13

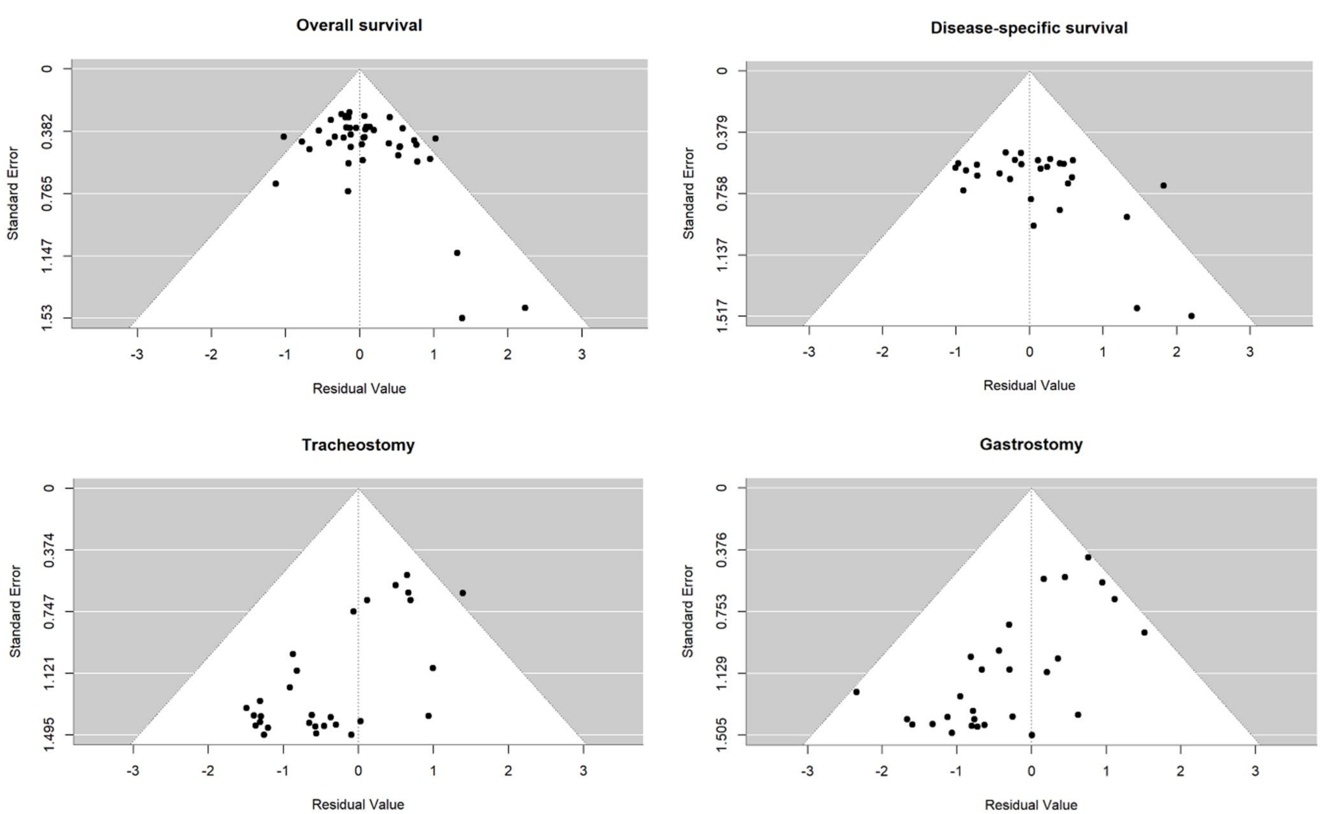


Fig. 3 Funnel Plot for OS, DSS, tracheostomy and gastrostomy. Other outcomes are presented in Annex 7

swallowing outcomes or QoL, as the scales and scores used were highly heterogeneous across studies.

One of the key and surprising findings was the limited number of studies evaluating IMRT (only two) in the treatment of supraglottic cancer. The existing literature often discussed IMRT outcomes more generally, including various head and neck subsites such as the oropharynx and nasopharynx, which have different prognosis compared to laryngeal tumors [14–18]. This knowledge gap highlights the need for more focused studies evaluating the specific outcomes of IMRT for supraglottic SCC. To address this limitation, we chose to include 2D/3D RT studies from the early 1990s to the present day in our analysis, as these would provide valuable comparative data. Within this RT group, we chose the year 2008 (the beginning of IMRT publications) and created three study groups: before 2008, containing/including 2008 and after 2008. We did not find significant differences between the groups, which aligns with the literature, showing that IMRT has similar oncological outcomes to 3D RT and may reduce of radiation-induced xerostomia and dysphagia [14–19].

Similarly, in 2025, the literature on TORS for supraglottic tumors remains limited ($n=8$), with no long term or QoL data. Most TORS publications focused on treatment of oropharyngeal cancer or general indication in the head and neck without individualized data on supraglottic cancer and were therefore excluded. Despite the limited number, TORS was included as an emerging technique; however, the small sample restricts the strength of conclusions and highlights the need for further comparative studies with TLM and RT.

Our preliminary oncological outcomes showed that OS significantly favored the surgical approaches, with TORS and TLM having better OS rates than RT (78% and 72% vs. 55% respectively). These results should be interpreted with caution due to potential heterogeneity among included studies, small number of patients in the TORS group and a vast majority of RT studies using old 2D/3D techniques rather than the modern, highly conformal IMRT that better spares normal tissues. While we were able to adjust for age and TNM stage, we were unable to account patients' comorbidities, particularly pulmonary status, which could bias the treatment choice (only three reported the Charlson Comorbidity Index [46, 48, 54]). Indeed, RT could be privileged for patients with contraindication for surgery due to medical comorbidities, potentially explaining the absence of significant difference in DSS [51]. Therefore, studies analyzing patient comorbidities are needed.

Over time, and with increasing team experience, the indications for transoral surgery (laser or robotic) have progressively expanded. In contrast to open partial surgery, advanced age is no longer considered as a formal contraindication [35, 64]. However, this evolution may have introduced a potential inclusion bias in the studies included, related to the gradual broadening of indications driven by growing surgical expertise, even within the same study team [65]. The meta-regression analysis comparing studies conducted before and after 2008 did not demonstrate a significant difference in outcomes. However, these findings should be interpreted with caution as a potential temporal bias cannot be excluded.

Another potential bias is the influence of adjuvant RT on reported outcomes. In several series, a high proportion of patients received postoperative RT, sometimes systematically, due to lymph node involvement, limiting the ability to evaluate the specific impact surgery on outcomes [66]. In our meta-regression, the addition of adjuvant RT in the surgical groups was associated with increased odds of poor functional outcomes, particularly for gastrostomy (OR 7.11). Poorer outcomes in irradiated patients could reflect either multiple treatments-related toxicity or more advanced disease that initially warranted adjuvant RT [64]. Future studies with more homogeneous treatment strategies, particularly limiting postoperative RT, are needed to allow meaningful comparisons.

Five-year DSS showed a trend favoring surgical approaches with 90% for TORS, 84% for TLM and 73% for RT which is consistent with a previous meta-analysis [26]. The results should be interpreted with caution given the relatively small number of patients in the TORS group, which may limit the robustness and generalizability of the findings. Anyway and by analogy, the same trends were observed in retrospective studies for oropharyngeal tumors, but this was not confirmed in prospective randomized controlled trials [67, 68]. Prospective randomized trials are needed and the results of the "Best Of" trial (which includes laryngeal tumors) will be key [69].

Data on swallowing outcomes were limited and highly heterogeneous, making comparisons between techniques challenging. The variety of assessment tools further complicated evaluations of short- and long-term swallowing outcomes.

Although forest plots showed here no significant difference, these findings should be interpreted cautiously. Objective swallowing data in the radiotherapy group remain scarce, with only one study reporting quantitative outcomes such as aspiration rates [70]. Tracheostomy practice lacks standardization, reflecting the absence of clear guidelines [71]. Some teams advocate systematic prophylactic tracheostomy to reduce aspiration risk [56], whereas others do not [31, 58, 72]. In addition, practices regarding timing of decannulation vary widely depending on institutional protocols, swallowing management, and access to speech therapy. Recent evidence suggests that the indication for prophylactic tracheostomy during TORS is multifactorial, with bilateral neck dissection as the main predictor, alongside age, nodal status, and tumor subsite [71]. These findings support a selective rather than routine use as a temporary protective measure. Future trials should incorporate standardized, objective criteria, as in the recent work by Ambrosch et al. [25] including validated swallowing scales and instrumental assessments such as FEES or videofluoroscopic examination. Well-designed multi-arm studies directly comparing TORS, TLM, and IMRT are also required.

Similarly, QoL data were heterogeneous, precluding meaningful comparisons. Retrospective QoL data is challenging due to missing baseline data and incomplete reporting [62], underscoring the need for prospective studies. Ambrosch et al. [25], reported a transient decrease in MDADI score following surgery, with recovery observed by 6 months. Adjuvant RT, tracheostomy or gastrostomy were associated with poorer short-term swallowing-related QoL. However, the correlation between objective swallowing impairment and patient-reported QoL remained weak, suggesting functional adaptation despite measurable deficits, consistent with previous findings [73].

This meta-analysis is the first to compare TORS, TLM and RT for early supraglottic SCC. Strengths include the large number of included studies, the up-to-date analysis, and rigorous data collection using a validated search strategy, with the protocol published prior analyses [37].

Limitations: Although pooled oncological outcome favored TORS and TLM over RT techniques, there are very few published studies examining outcomes after TORS and IMRT. Furthermore, the data was heterogeneous due to imbalances in patient numbers between groups, missing data and lack of randomized studies. Furthermore, selection bias and surgeon/teams-specific effects among single-institution studies could introduce bias. Individual patient data were unavailable for pooling in this meta-analysis which was based primarily on summary data extracted from published trials. Moreover, as in many retrospective studies, changes in patient management over time may introduce temporal heterogeneity in functional outcomes and QoL, complicating interpretation of outcomes [65, 74]. Therefore, further prospective head-to-head studies with validated assessment tools are required to obtain answers on functional and QoL data.

Conclusions

In conclusion, our comprehensive meta-analysis suggests that TLM and TORS appear to be associated with improved overall survival compared to historical (outdated) 2D RT techniques, with similar functional results. Further prospective comparison of modern IMRT and TORS is needed, based on more robust studies including a larger number of patients. In line with other studies, the functional outcomes in case of adjuvant RT are worse. However, the effect on QoL and swallowing data remain limited and heterogeneous, highlighting the need for future prospective studies with multiple treatment arms, comorbidities analysis and validated scale assessments to better evaluate these crucial patient-reported outcomes.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

AI statement Generative AI and AI-assisted technologies were NOT used in the preparation of this work.

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