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Review

Surgical, Functional, and oncological outcomes of transoral robotic surgery for cT1-T3 supraglottic laryngeal Cancers: A systematic review

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ABSTRACT

Background: This systematic review investigated the surgical, functional, and oncological outcomes of transoral robotic supraglottic laryngectomy (TORS-SGL) for cT1-T3 laryngeal squamous cell carcinoma (LSCC).
Methods: Two investigators conducted an updated PubMed, Scopus, and Cochrane Library systematic review for studies investigating the surgical, functional, and oncological outcomes of TORS-SGL using the PRISMA statements. The bias analysis was conducted with the MINORS.
Results: Twenty-one studies were included, accounting for 896 patients. TORS-SGL was primarily performed for cT1 (39.1 %), cT2 (46.9 %), and some selected cT3 (7.7 %) LSCCs. Surgical margins were positive in 10.8 % of cases. The mean hospital stay was 8.6 days. Hemorrhage (6.3 %), pneumonia (5.5 %), and aspiration (1.7 %) are the primary complications. The surgical margins were positive in 10.6 % of cases. Feeding tubes, temporary tracheotomy, and definitive percutaneous gastrostomy are found in 65.6 %, 19.7 %, and 5.2 % of patients, respectively. The oral diet is restarted after a mean of 7.2 days. The 5-year OS and DFS of TORS-SGL were estimated to be 78.3 %, and 91.7 %, with 5-year local-relapse-free survival and nodal-relapse-free survival of 90.8 %, and 86.6 %, respectively.
Conclusion: The TORS-SGL is a safe, and effective surgical approach for cT1-T3 SGL. The functional and surgical outcomes appear comparable with TOLM-SGL. The oncological outcomes of TORS-SGL could be better than TOLM and open SGLs, but further large cohort-controlled studies are needed to draw reliable conclusions.

Introduction

Laryngeal squamous cell carcinoma (LSCC) is the second most common head and neck squamous cell carcinoma, accounting for 211,000 new cases and 126,000 deaths per year worldwide [1,2]. The supraglottic LSCC corresponds to one-third of all LSCCs [3]. Radiotherapy and partial laryngectomy are considered as the standard of care for early-stage supraglottic LSCCs [4]. In the past decades, the development of transoral laser microsurgery (TOLM) and transoral robotic surgery (TORS) changed the surgical practice in the management of SGL with better functional, surgical outcomes than open partial laryngectomy, while comparable oncological outcomes [5–7]. In 2019, our international group conducted a systematic review dedicated to functional, and oncological outcomes of TORS-SGL [7]. This review provided important findings for functional and surgical outcomes, but the data were limited for oncological outcomes given the recent spread of Da Vinci robots and the related delay in publishing TORS studies, which did not report an adequate follow-up duration [7]. According to the growing literature about TORS-SGL in the past few years, the present systematic review aimed to update the functional, surgical, and oncological outcomes associated with TORS-SGL for cT1-T3 supraglottic LSCCs.

Materials and methods

The steps of the systematic review were conducted according to the

Abbreviations: DFS, disease-free survival; EBL, evidence level; LSCC, laryngeal squamous cell carcinoma; OS, overall survival; TOLM, transoral laser microsurgery; TORS, transoral robotic surgery; SGL, supraglottic laryngectomy.

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Preferred Reporting Items for a Systematic Review and Meta-analysis (PRISMA) checklist [8]. The criteria for considering studies were based on the population, intervention, comparison, outcome, timing, and setting (PICOTS) framework [9].

Studies: The systematic review included prospective and retrospective, cancer database cross-sectional, controlled, uncontrolled, or randomized studies published in English-language peer-reviewed journals between January 2007 and August 2024. The authors had to explore the safety and effectiveness of TOLM-SGL through surgical, functional, or survival outcomes. The single case reports and preliminary studies on animals or cadavers were not considered in this review. Only the studies reporting data for ≥ 3 cases have been considered.

Participants and inclusion criteria: The data related to the types and clinical stages of supraglottic LSCC, and inclusion and exclusion criteria were carefully reviewed for including studies in the review. The authors reporting data for glottic and supraglottic LSCC had to specify subgroup data for TORS-SGL. According to some recent consensus related to the indication of minimal invasive surgical treatment for supraglottic LSCC [9], the studies reporting outcomes for cTis, cT1, T2, and T3 LSCC were considered. Studies describing TORS findings for cT4 supraglottic LSCC, including TORS-total laryngectomy, were not included regarding the lack of consensus for treating cT4 LSCC with TORS.

Outcomes: The extracting data were subdivided into the 4 following groups: demographics, surgical, functional, and survival outcomes. Demographics consisted of mean/median age and gender ratio. Surgical outcomes included tumor stage (c/pTNM), anatomical sublocation, margin status, neck dissection details, additional treatments (chemo/radiotherapy), laryngeal preservation rate, hospital stay, postoperative complications, the type of SGL regarding the European Laryngological Society Classification [10]. The investigators only included complications related to the surgical procedure, excluding tardive complications associated with postoperative chemo/radiotherapy. The functional outcomes consisted of the findings related to temporary or permanent tracheotomy, decannulation time, feeding tube, temporary and permanent gastrostomy, and time for re-starting oral diet. The following oncological outcomes were reviewed: the mean/median follow-up time, overall survival (OS), disease-free survival (DFS), the local and regional control rates (number of local/regional recurrences or local/regional relapse-free survival), and the incidence of distant metastases. Note that some surgical outcomes (e.g., setup time, surgical time, blood loss), which were extensively investigated in the 2019 review [7], were not re-investigated in the present review given the potential lack of trend change over the past five years.

Intervention and comparison: The TORS-SGLs were considered as surgical procedures. The ELS classification includes types I to IV SGL. Type I is the resection of small and superficial tumors of the free edge of the epiglottis, the aryepiglottic fold, the arytenoid, the ventricular band, or any other part(s) of the supraglottis. Type II consists of a medial SGL without resection of the pre-epiglottic space. Type III is a medial SGL with the resection of the pre-epiglottic space. Type IV is a lateral SGL procedure for tumors of the anterior region of the aryepiglottic fold, including the ventricular band, arytenoid unit, and the inner, medial, or anterior part of the piriform sinus [10].

Timing and Setting: There were no criteria for specific timing in the disease process. The cTis and cT1 tumor stages were pooled into a cT1 group.

Search strategy

The PubMed, Scopus, and Cochrane Library searches were conducted by the author and a librarian for relevant peer-reviewed publications related to surgical, functional, and oncological outcomes of TORS-SGL. The studies included in the 2019 systematic review [7] were included, but the investigators re-evaluated the entire literature for potential missing publications. The following keywords were used for the search strategy: Larynx; Laryngeal; Supraglottic; Transoral; Robotic; Surgery; Partial Laryngectomy; Surgical; Cancer; Squamous Cell Carcinoma; Oncological; Survival; Outcome; and Complications. The studies reporting database abstracts, available full-texts, or titles containing the search terms were considered. The research strategy findings were reviewed for relevance and the reference lists of some articles (e.g., reviews or *meta*-analyses) were examined for additional pertinent studies. The included studies were analyzed for the number of patients, study design, inclusion and exclusion criteria, quality of trial/evidence-based level (EBL), demographics, follow-up, and outcomes. The investigators paid critical attention to the potential overlap between cohort studies. Ethics committee approval was not required.

Bias analysis

The bias analysis was conducted with the MINORS tool, which is a validated instrument designed for assessing the quality of retrospective, prospective, uncontrolled, controlled, or randomized surgical studies [11]. MINORS includes items rated 0 if absent, 1 when reported but inadequate, and 2 when reported and adequate. The following items compose the MINORS: i) aim of the study (clearly stated (2), unclear (1), or absent (0)); ii) inclusion of patients (consecutive (2) or not (0) inclusion); iii) prospective data collection (perfectly prospective (2), retrospective analysis of prospective collected data (1), or absent (0)); iv) appropriateness of endpoints (evaluation of functional, surgical, and oncological outcomes (2), evaluation of one or two outcomes (1), partial evaluation of one outcome group (0)); v) adequate follow-up period (adequate time for getting 5-year survival outcomes (2), 2-year survival (1), or less (0)); and vi) the 5 % rate of lost to follow-up ((2) versus (0) if more than 5 %). The item related to the study size prospective calculation was only considered for prospective studies and judged as good (2), mentioned as unnecessary or not provided (1), or absent (0). The ideal MINORS score was 16 for non-comparative studies and 24 for comparative studies [11].

Results

Of the 129 identified studies, 21 studies met our inclusion criteria (Fig 1) [12–32]. Six studies were prospective (EBL: C) [12,13,15,19,27,30], and the others were retrospective (EBL: D) (Table 1). Two studies report data from a National Cancer Database [29,31]. There was no study excluded for the inclusion of cT4 supraglottic LSCC. Of the 2020–2024 studies, 3 papers were excluded in the selection process for inclusion of data of glottic and supraglottic LSCCs without subgroup details [33–35]. The TORS-SGL of Sampieri *et al.* was excluded because the authors included TORS-SGL patients with neoadjuvant chemotherapy before the surgery [36]. The study of Zorzi *et al.* was not included regarding the pooling of data of TOLM and TORS-SGL within a single group [37]. Compared to the 2019 review, seven additional studies were therefore included in the present systematic review, including data from 386 additional patients [15,20,22,30–32]. Functional, surgical, and oncological outcomes are reported in Tables 1 and 2.

Demographics, Patients, and tumor stages

A total of 896 patients underwent TORS-SGL. There were 81 females and 632 males. The mean age of patients was 60.5 years, ranging from 54.3 to 68.0 years (Table 1). The anatomical sublocation of LSCC was reported for 186 patients, including epiglottis (n = 81, 43.5 %), aryepiglottic fold (n = 39, 21.0 %), and false vocal cords (n = 16, 8.6 %) as the primary sites (Table 3) [15,17–19,24,25,27]. Considering studies where the cT stage was specified, the TORS-SGL was performed in patients with cT1 (n = 342/874; 39.1 %), cT2 (n = 410/874; 46.9 %), and cT3 (n = 69/896; 7.7 %) supraglottic LSCCs, respectively. Al-Qurayshi *et*

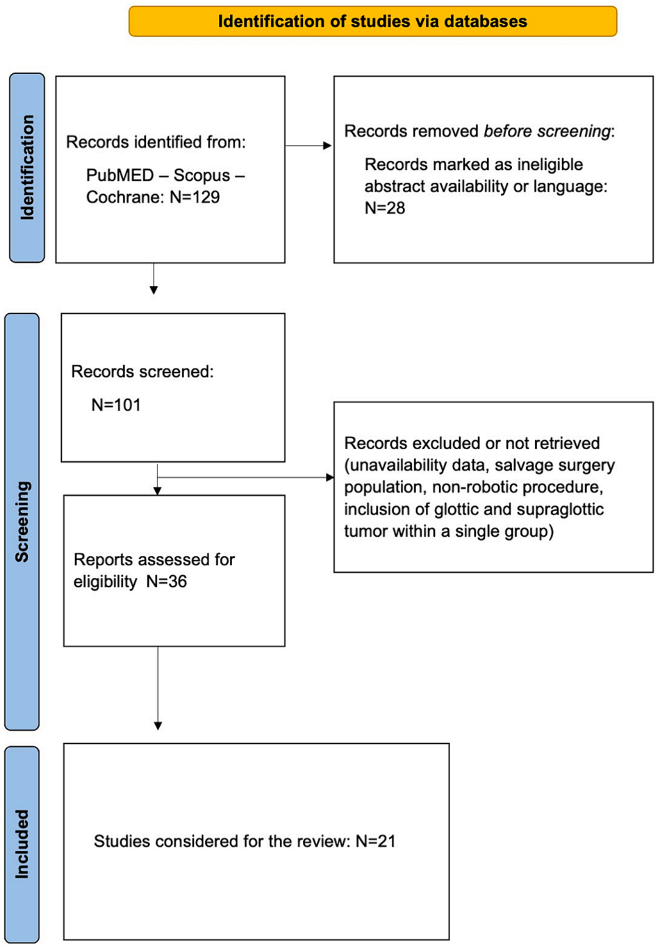

Figure 1. PRISMA flowchart.

al. only included data for cT1-T2N0 patients [29], while Kayhan *et al.* focused on outcomes of cT1N0 patients [20]. The node status was reported in detail in 13 studies [14,15,17,18,20–22,26–30,32]. TORS-SGP was commonly performed in patients with cN0 (n = 545/825; 66.1 %), and cN1 (n = 85/815; 10.4 %) LSCCs. Note that there were only 2/530 (0.4 %) patients undergoing TORS-SGL with cN3 (Table 4).

Surgical Outcomes, adjuvant Therapies, and complications

The surgical outcomes were reported in 20 studies (Table 1) [12–28,30–32]. The type of TORS-SGL was specified for 355 patients, including types I (n = 33, 9.3 %), II (n = 67, 18.9 %), III (n = 84, 23.7 %), III-V (n = 2, 0.1 %) and IV (n = 168, 47.3 %) ELS-SGL, respectively [15,16,21,26–28]. Surgical margins were positive in 81/767 cases (10.6 %). Of the studies providing neck dissection details (n = 329), unilateral and bilateral neck dissections were carried out in 56 (17.0 %) and 231 (70.2 %) cases (Table 1). Some authors reported the number of neck dissections without specifying the uni- or bilaterality [16,17,21,26], while others did not report the number of neck dissection(s) [20,29,31]. The laryngeal preservation rate ranged from 95.6 % to 100 % (Table 1). A total of 304/754 (40.3 %) patients were treated with postoperative radiotherapy or chemoradiotherapy. The mean hospital stay was 8.6 days (n = 673; Table 1).

The review of postoperative complications is reported in Table 5. Four studies did not detail the occurrence or the types of complications [15,23,29,31]. Doazan *et al.* only reported lethal complications [26]. The primary complications of TORS-SGL were hemorrhage (n = 34; 6.3 %), pneumonia (n = 28; 5.5 %), and aspiration without pneumonia (n = 9; 1.7 %).

Functional outcomes

Functional outcomes were partly or fully reported in 18 studies [12–25,27,28,30,31]. The tracheotomy was systematically carried out in only two studies [14,19]. Of the 15 studies providing detailed information, a tracheotomy was temporarily performed in 81/411 (19.7 %) patients for a mean decannulation time of 9.3 days (Table 1). The decannulation was not carried out in 7/397 patients, corresponding to a definitive tracheotomy rate of 1.8 % of TORS-SGL patients. A feeding tube was used in 248/378 (65.6 %) patients, while percutaneous gastrostomy was temporarily and definitively required in 15/344 (4.4 %), and 18/344 (5.2 %) patients, respectively. The oral diet was restarted after a mean of 7.2 days (n = 358; Table 1).

Survival outcomes

The oncological outcomes are available in Table 2. Four studies did not report survival outcomes [12,13,22,24]. The mean follow-up was 32.6 months (95 %CI: 16.3–49.0). The 2-year OS, and DFS were 86.2 % (n = 199 patients), and 94.0 % (n = 215 patients), respectively. The 5-year survival data were available in 5 studies, 3 being published in the last 4 years [26,28,29,31,32]. The 5-year OS and DFS were 78.3 % (n = 535), and 91.7 % (n = 220), respectively. The 5-year local-relapse-free survival and nodal-relapse-free survival were 90.8 % (n = 220), and 86.6 % (n = 220), respectively. Some studies reported the numbers of local and regional recurrences [16–19,21,23,25]. In these studies, there were 5/158 (3.2 %) patients with local recurrence (mean follow-up of 21.8 months (95 %CI: 15.4–28.2)), and 1/175 (0.6 %) patients with regional recurrence (mean follow-up of 22.5 months (95 %CI: 17.5–28.0)), respectively. Metastasis was detected in 16/209 patients (7.7 %) in the mean follow-up period (14.5–60.0 months).

Epidemiological analysis

The mean MINORS was 7.1 ± 2.3 (Table 6). The inclusion of consecutive patients was not specified in 8 studies [12,17–20,27,29,32] and the proportion of lost-to-follow-up was not reported in 10 studies [13,17,19–21,23–25,27,32]. No prospective or retrospective database study detailed a study size calculation before conducting the investigation. The majority of studies presented unbiased endpoint assessment for surgical, functional, and/or oncological outcomes. The lack of inclusion of consecutive patients in a prospective design with adequate follow-up and study size calculation are the primary points supporting the low MINORS in studies. The MINORS analysis revealed several degrees of heterogeneity across studies for the inclusion criteria, tumor features, postoperative care, follow-up, complications, and surgical features. Patients who underwent previous head and neck radiation [26,27] or surgical procedures were excluded in some studies [12], while others included patients with a history of laryngopharyngeal surgery [16,21,26], or head and neck radiation [16,21]. Most authors included patients with LSCC, but the bias analysis reports the inclusion of adenosquamous and mucoepidermoid carcinomas in one study [24]. As above-mentioned, two teams did not investigate outcomes in cT1-T3 LSCC but focused on specific staging [20,29]. From a surgical point of view, it was difficult to evaluate the method used to document the postoperative complications because most authors just reported a list of complications without providing a systematic evaluation of other complications. The systematic requirement of feeding tubes and tracheotomy in some studies [14,19] can bias the evaluation of the need for tracheotomy and feeding diet in TORS-SGL.

Discussion

The rapid evolution of robotic technologies and the increasing use of TORS in head and neck surgery make important the transversal evaluation of surgical, functional, and oncological outcomes in TORS-SGL.

Table 1
Surgical and Functional Outcomes.

			Demographics				Adj. C/RT	Surgical outcomes			Functional outcomes				
References	Design	EBL	N	F/M	Age (y)	U/BND	N (%)	LP (%)	Margins+ (N)	HS (d)	t/p TC (N)	Deca (d)	Feeding (N,%)	t/p GA (N)	Oral Diet (d)
Weinstein, 2007 [12]	Prospective	C	3	1/2	62.3	0/3	1 (33.3)	100	0 (100)	5.3	0/0	–	0 (0)	0/0	37.1
Alon, 2010 [22]	Retrospective	D	7	3/4	61.0	0/4	2 (28.6)	100	0 (0)	5.0	3/1	4–45	3 (42.9)	2/0	–
Ozer, 2012 [13]	Prospective	C	13	6/7	58.0	0/12	2 (15.4)	100	0 (100)	3.9	1/0	17.0	1 (7.7)	0/0	1.0
Olsen, 2012 [14]	Retrospective	D	9	2/7	61.9	3/6	6 (66.7)	100	0 (100)	–	7/2	–	4 (44.4)	0/4	–
Mendelsohn, 2012 [15]	Prospective	C	18	4/14	–	2/4	8 (44.4)	100	0 (0)	11	0/0	–	–	0/0	5.5
Ansarin, 2013 [16]	Retrospective	D	10	1/9	68.0	10	9 (90)	–	4 (40.0)	13.0	9	–	7 (70.0)	1/0	12.0
Lallemant, 2013 [17]	Retrospective	D	23	1/22	61.0	11	4 (17.4)	95.6	1 (5.2)	9.0	2/0	3.5	19 (82.6)	1/0	10.0
Oysu, 2013 [18]	Retrospective	D	3	1/2	54.3	2/0	2 (66.7)	100	0 (100)	–	0/0	–	3 (100)	0/0	8.3
Park, 2013 [19]	Prospective	C	16	1/15	66.0	8/6	8 (50.0)	100	0 (100)	13.5	16	11.2	16 (100)	–	8.3
Kayhan, 2014 [20]	Retrospective	D	13	1/12	60.0	–	+	100	0 (0)	15.4	0/0	–	13 (100)	0/0	10.8
Razafindranaly, 2015 [21]	Retrospective	D	84	16/68	59.0	67	63 (75.0)	–	8 (9.5)	15.1	20/1	8.0	64 (76.2)	0/8	8.0
Slama, 2016 (23)	Retrospective	D	22	5/17	59.0	0/22	+	–	–	–	–	–	22 (100)	–	–
Stubbs, 2018 [24]	Retrospective	D	63	23/40	63.6	10/36	+	–	–	5.0	20/0	12.2	–	–	–
Karabulut, 2018 [25]	Retrospective	D	17	2/15	62.0	0/17	13 (76.5)	100	0 (100)	8.8	0/0	–	17 (100)	0/0	7.0
Doazan, 2018 [26]	Retrospective	D	122	29/93	60.0	112	63 (51.6)	–	8 (6.6)	–	–	–	–	–	–
Dabas, 2019 [27]	Prospective	C	46	2/44	63.0	0/46	26 (56.5)	100	12 (26.7)	10.3	21/3	6.3	34 (73.9)	11/6	8.4
Hans, 2020 [28]	Retrospective	D	75	13/62	58.0	31/38	6 (8.0)	100	4 (5.3)	6.8	6/0	–	8 (10.7)	0/0	2.0
Al-Qurayshi, 2021 [29]	Retrospective	D	44	21/23	–	+	–	–	–	–	–	–	–	–	–
Kaya, 2022 [30]	Prospective	C	14	1/13	62.5	0/14	3 (21.4)	–	0 (0)	14.1	0/0	–	14 (100)	–	10.5
Papazian, 2023 [31]	Retrospective	D	271	97/174	62.0°	–	73 (26.9)	–	44 (16.2)	6.8	–	–	–	–	–
Muderis, 2024 [32]	Retrospective	D	23	3/20	58.1	0/23	15 (65.2)	100	0 (0)	–	1/0	13.0	23 (100)	0/0	10.3

Some values were median°; the others being mean, percentages, or numbers. Abbreviations: Adj. = adjuvant; d = days; Deca = decannulation timing; EBL = evidence-based level; F/M = female/male; FT = feeding tube; GA = gastrostomy; HS = hospital stay; LP = laryngeal preservation; mo = month(d); N = number; PM = positive margins; RT = radiotherapy; t/p TC = temporary/permanent tracheotomy; U/BND = primary unilateral/bilateral neck dissection(s); y = years.

Compared to the previous systematic review conducted in 2019 [7], the present review includes 7 additional studies corresponding to data of 386 patients reporting longer follow-up than those of the 2019 paper.

The safety of TORS-SGL in terms of surgical outcomes can be confirmed with a low rate of postoperative complications, including bleeding (6.3 %), pneumonia (5.5 %), and aspiration (1.7 %). In a recent systematic review investigating surgical outcomes of 937 TOLM-SGL patients, the more common complications consisted of aspiration (5.5 %), bleeding (5.3 %), granulation tissue (4.1 %), and pneumonia (3.0 %) [38], which is comparable with the TORS-SGL findings. The complication rates of TORS and TOLM-SGL are however lower than those found for open SGL. Indeed, Karatzanis *et al.* observed in a comparative study between TOLM and open SGL that endoscopic procedures were associated with a lower incidence of major complications, permanent gastrostomies, and tracheotomies compared with open techniques [39]. Similar findings have been reported by Canis *et al.* who suggested that the lower complication rates after TOLM may be attributed to the preservation of healthy tissue and functionally important structures [40]. The low rate of complications in TORS-SGL populations can support the short hospital stay. In the present review, the mean calculated hospital stay of TORS-SGL studies was 8.6 days, which is lower than those reported for TOLM-SGL (10.1 days) [38] or open SGL (6–24.9 days) [41,42]. This observation was in agreement with the data of Park *et al.* who compared the surgical outcomes of TORS-SGL and open SGL, reporting an average hospital stay of 18.6 days and 24.9 days for TORS and TOLM groups, respectively [41]. Despite the excellent surgical outcomes of TORS and the potential superiority of TORS and TOLM over open SGL, it remains difficult to draw definitive conclusions because the hospital stay is commonly influenced by numerous confounding factors, including the profile of patients (comorbidities), age, tumor stages, and the previous surgical or radiation treatments [43–46]. The risk of confounding factors was particularly highlighted in our bias analysis regarding the heterogeneity between studies in terms of patient population, inclusion criteria, and comorbidities. In addition, the potential superiority of TORS over TOLM and open SGL could be tempered regarding the National Cancer Database study of Papazian *et al.* who reported a significantly higher rate of 30-day unplanned readmission in TORS-SGL group (7.8 %), compared to TOLM (1.2 %), and open SGL (4.2 %) [31].

From a functional standpoint, the rates of temporary tracheotomy, feeding tubes, and definitive percutaneous gastrostomy of TORS-SGL were evaluated to be 19.7 %, 65.6 %, and 5.2 %, respectively. In

Table 2
Oncological Outcomes.

References	Design	N	Stages (N) c/pT1-T2-T3	N+ (%)	Adj. RT N (%)	Survival outcomes TA	OS	DFS	LRec	NRec (N, %)	DM (N, %)	FU (mo)
Weinstein, 2007 [12]	Prospective	3	0–2-1	–	1 (33.3)	–	–	–	–	–	–	–
Alon, 2010 [22]	Retrospective	7	2–4-1	4	2 (28.6)	–	–	–	–	–	–	–
Ozer, 2012 [13]	Prospective	13	1–10-2	–	2 (15.4)	–	–	–	–	–	–	6.8
Olsen, 2012 [14]	Retrospective	9	1–6-2	5	6 (66.7)	2y	66.7	87.5	100	87.5	0	26.0
Mendelsohn, 2012 [15]	Prospective	18	5–10-3	10	8 (44.4)	2y	89.0	100	100	83.0	4	28.1
Ansarin, 2013 [16]	Retrospective	10	2–6-2	4	9 (90)	2y	100	100	1	0	0	25.0
Lallemant, 2013 [17]	Retrospective	23	16–7-0	3	4 (17.4)	15 mo	100	100	2	0	0	15.7
Oysu, 2013 [18]	Retrospective	3	3–0-0	2	2 (66.7)	14 mo	–	–	0	0	–	14.0
Park, 2013 [19]	Prospective	16	7–5-4	–	8 (50.0)	2y	–	91.0	0	0	1	20.3
Kayhan, 2014 [20]	Retrospective	13	13–0-0	0	5 (38.5)	–	–	–	100	100	1	14.5
Razafindranaly, 2015 [21]	Retrospective	84	29–46-9	30	63 (75.0)	14 mo	–	–	2	0	–	14.0°
Slama, 2016 [23]	Retrospective	22	22–0	–	+	34 mo	–	–	0	1	1	34.0
Stubbs, 2018 [24]	Retrospective	63	9–26-10	13	+	–	–	–	–	–	–	49.7
Karabulut, 2018 [25]	Retrospective	17	5–4-8	–	13 (76.5)	25.8 mo	88.0	94.0	–	1	–	25.8
Doazan, 2018 [26]	Retrospective	122	44–62-16	46	63 (51.6)	2/5y	86.9–78.7	95.1–94.3	94.3–90.2	91.8–87.7	–	48.2
Dabas, 2019 [27]	Prospective	46	22–24-0	0	26 (56.5)	41 mo	88.9	84.4	5		–	41.0
Hans, 2020 [28]	Retrospective	75	16–21-5	18	6 (8.0)	5y	80.2	94.3	93.2	89.2	5	60.0
Al-Qurayshi, 2021 [29]	Retrospective	44	26–18-0	0	+	5y	87.6	–	–	–	–	38.6
Kaya, 2022 [30]	Prospective	14	8–6-0	3	3 (21.4)	–	–	–	0	–	–	6.0
Papazian, 2023 [31]	Retrospective	271	131–140-0	70	73 (26.9)	5y	77.8	–	–	–	–	58.4
Muderis, 2024 [32]	Retrospective	23	2–13-6	14	15 (65.2)	2/5y	81.0–57.1	85.7–69.3	94.4–85.9	90–72.2	4	48.8

Some values were median (°). For local and regional recurrence, some authors reported local-relapse-free survival or nodal-relapse-free survival (#), Abbreviations: Adj. = adjuvant; d = days; DFS = disease-free survival; DM = distant metastasis; FU = follow-up; mo = month(d); N = number; PM = positive margins; L/N.FRec = local/nodal free recurrence rate; OS = overall survival; RT = radiotherapy; SPS = Swallowing Performance Status Scale; TA = time of assessment (survival outcomes); y = years.

Table 3
Anatomical Location of Tumors.

References	N	Epiglottis	FVC +/- VC	Epiglottis + Vallecula	Epiglottis + AEF	Epiglottis + BT + AEF	Epiglottis + FVC	Epiglottis + BT + FVC + AEF	AEF	Epiglottis + FVC + AEF	Arytenoid+ AEF + FVC	Arytenoid+/- FVC
Lallemant, 2013 [17]*	23	2	13	0	2	1	1	0	2	0	2	0
Oysu, 2013 [18]	3	3	0	0	0	0	0	0	0	0	0	0
Park, 2013 [19]	16	10	2	0	0	0	0	0	4	0	0	0
Stubbs, 2018 [24]	63	36	1	0	0	0	0	0	9	0	0	3
Karabulut, 2018 [25]	17	9	0	2	4	0	2	0	0	0	0	0
Dabas, 2019 [27]	46	16	0	6	0	0	0	0	22	0	0	0
Mendelsohn, 2012 [15]	18	5	0	0	3	0	6	1	2	1	0	0
Total	186	81	16	8	9	1	9	1	39	1	2	3

*Lallemant *et al.* provided data for vocal cord invasion of LSCC treated with TORS-SGL. Abbreviations: AEF = aryepiglottic fold; BT = base of the tongue; FVC = false vocal cords; N = number; T = tumor.

TOLM-SGL, these rates were estimated to be 18.0 %, 59.9 %, and 2.4 %, respectively [38]. Interestingly, the TOLM data reported that practitioners tended to decrease the use of feeding tubes over time, which could be observed in further studies in TORS [38]. This point was highlighted by the findings of Chiesa-Estomba *et al.*, who restarted the oral diet after 6–48 h in all cT1-T3 supraglottic LSCC patients undergoing TOLM-SGL without signaling substantial complications [47]. In our experience [28], surgeons tend to use feeding tubes or tracheotomy for their first TORS-SGL, while when achieving experience, they select the cases (cT3-aging patients) requiring preventive tracheotomy or feeding tubes. The optional requirement of tracheotomy in TORS-SGL was supported in the systematic review of Chiari *et al.* who observed across 8 studies that 25 % of patients undergoing TORS-SGL had temporary tracheotomy [48]. For feeding and gastrostomy tubes, Caporale *et al.* compared the functional outcomes of 11 TORS-SGL studies with 14 open SGL studies [49]. The authors reported the superiority of TORS over open partial laryngectomy in terms of functional outcomes and feeding tube/percutaneous gastrostomy requirements [49]. These authors showed that a feeding tube was placed in 58 % of patients treated with TORS, whereas 100 % of patients undergoing open partial laryngectomy underwent feeding tube placement, which was removed after 9 and 36 days in patients undergoing TORS and partial laryngectomy,

Table 4
Tumor Stages.

References	N	T stage cT1-is	cT2	cT3	N stage N0	N1	N2a	N2b	N2c	N3
Weinstein, 2007 [12]	3	0	2	1	–	–	–	–	–	–
Ozer, 2012 [13]	13	1	10	2	–	–	–	–	–	–
Olsen, 2012 [14]	9	1	6	2	4	0	0	4	1	0
Ansarin, 2013 [16]	10	2	6	2	6	4				
Lallemant, 2013 [17]	23	16	7	0	20	1	0	1	1	0
Oysu, 2013 [18]	3	3	0	0	1	0	1	1	0	0
Park, 2013 [19]	16	7	5	4	–	–	–	–	–	–
Razafindranaly, 2015 [21]	84	29	46	9	54	11	4	9	5	1
Slama, 2016 [23]	22	22		0	–	–	–	–	–	–
Stubbs, 2018 [24]	63	9	26	10	41	3	10			0
Karabulut, 2018 [25]	17	5	4	8	–	–	–	–	–	–
Doazan, 2018 [26]	122	44	62	16	76	19	9	11	6	1
Dabas, 2019 [27]	46	22	24	0	46	0	0	0	0	0
Hans, 2020 [28]	75	16	21	5	24	8	7	1	2	0
Mendelsohn, 2012 [15]	18	5	10	3	8	2	0	5	3	0
Alon, 2010 [22]	7	2	4	1	3	2	0	1	1	0
Muderis, 2024 [32]	23	2	13	6	7	5	4	3	2	0
Kayhan, 2014 [20]	13	13	0	0	0	0	0	0	0	0
Papazian, 2023 [31]	271	131	140	0	200	32	38			<10
Kaya, 2022 [30]	14	8	6	0	11	2	1			0
Al-Qurayshi, 2021 [29]	44	26	18	0	44	0	0	0	0	0
Total number	896	342	410	69	545	85	25	36	21	2

*In the study of Stubbs, 6 recurrence cancers were not associated with a cTNM stage. Abbreviations: N = number; T = tumor.

Table 5
Complications.

References	N	Bleeding	Aspiration	Pneum.	Stenosis	SE	MI	Fistula	Hematoma	LE	Pn.Thorax	PE	DT	TSI
Weinstein, 2007 [12]	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Ozer, 2012 [13]	13	0	0	1	0	0	0	0	0	1	0	0	0	0
Olsen, 2012 [14]	9	1	0	0	1	0	0	0	0	0	0	0	0	0
Ansarin, 2013 [16]	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Lallemant, 2013 [17]	23	1	0	0	0	1	0	0	0	0	0	0	0	0
Oysu, 2013 [18]	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Park, 2013 [19]	16	0	1	0	0	0	0	0	0	0	0	0	0	0
Razafindranaly, 2015 [21]	84	15	0	19	0	0	0	1	0	0	0	0	0	0
Stubbs, 2018 [24]	63	1	0	0	0	0	1	0	0	2	0	0	0	0
Karabulut, 2018 [25]	17	0	0	0	0	0	0	0	0	0	1	0	0	0
Doazan, 2018 [26]	122	2	–	3	–	–	–	–	–	–	–	1	–	–
Dabas, 2019 [27]	46	2	2	0	0	0	0	0	0	0	0	0	0	0
Hans, 2020 [28]	75	12	–	3	0	0	0	0	3	0	0	0	1	0
Alon, 2010 [22]	7	0	0	0	0	0	0	0	0	0	0	0	0	1
Muderis, 2024 [32]	23	0	0	0	0	0	0	0	0	0	0	0	0	0
Kayhan, 2014 [20]	13	0	0	2	1	0	0	0	0	0	0	0	0	0
Kaya, 2022 [30]	14	0	0	2	0	0	0	0	0	0	0	0	0	0
Total	541	34	3	30	2	1	1	1	3	3	1	1	1	1

In the study of Olsen *et al.*, bleeding occurred in the tracheotomy orifice. In the study of Doazan *et al.*, authors reported only lethal complications. Abbreviations: DT = delirium tremens; LE = laryngeal edema; MI = Myocardial infarction; PE = pulmonary embolism; Pneum. = pneumonia; Pn.Thorax = pneumothorax; TSI = Thermal skin injury; SE = subcutaneous emphysema.

respectively [49]. In the same way, percutaneous gastrostomy was less frequently required in TORS-SGL patients compared to open SGL, with a maximum of 10 % of TORS patients and 29 % in open SGL [49]. The establishment of international consensus in the indications of tracheotomy and feeding tubes in TORS-SGL could guide the head and neck surgeons who aim to start using surgical robots because these functional outcomes have a significant impact on the hospital stay, complications, and the related cost burden for patients and healthcare systems.

The primary finding of the present systematic review was the determination of OS and DFS data for TORS-SGL, which was difficult in the 2019 review due to the lack of studies with a long-term follow-up [38]. The combined analysis suggests that TORS-SGL is associated with 2-year and 5-year OS of 86.2 % and 78.3 %, respectively. Considering DFS, the 2-year and 5-year rates were 94.0 % and 91.7 %, respectively. These data are substantially higher than those found in the systematic review dedicated to the 5-year OS and DFS of TOLM-SGL (OS: 70.1 % and DFS: 82.1 %) [38]. The 5-year local-relapse-free survival and nodal-relapse-free survival were 90.8 %, and 86.6 % for TORS-SGL, and ranged from 83.0 % to 97.0 % for TOLM-SGL, respectively [38]. Although there is no large cohort prospective study comparing both approaches, the potential better survival outcomes of TORS-SGL over TOLM-SGL were supported by the National Cancer Database study of Papazian *et al.* who observed a 5-year OS of 77.8 % for TORS-SGL group. In comparison, the OS of TOLM and open SGL were 67.7 % and 66.1 %, respectively. The higher survival outcomes of TORS group could be linked with the surgical outcomes and, particularly, the margin status, which appears to be better in TORS compared to TOLM [38] and open SGL groups [31]. Indeed, TORS-SGL should be associated with a negative margin rate of 80.1 %, while the margins are negative in 48.8 %, and 74.1 % of cases from TOLM and open surgery groups [31]. The observations of Papazian *et al.* are corroborated in the comparison of margin outcomes between the present review and the TOLM-SGL review where the mean positive margin rate was 13.6 % [38]. Among the surgical outcomes supporting the potential advantages of TORS, further studies could investigate the

Table 6
MINORS analysis.

References	Clearly Stated Aim	Inclusion of consecutive patients	Prospective data collection	Endpoints appropriate to study	Unbiased endpoint assessment	Follow-up adequate period	<5% of lost of follow-up	Study size prospective calculation	Total MINORS score
Weinstein, 2007 [12]	2	–	2	1	2	0	2	0	9
Alon, 2010 [22]	1	2	0	2	2	0	2	0	9
Ozer, 2012 [13]	2	0	2	1	2	0	–	0	7
Olsen, 2012 [14]	1	2	1	2	2	1	2	0	11
Mendelsohn, 2012 [15]	1	2	2	2	2	1	2	0	12
Ansarin, 2013 [16]	2	0	0	1	1	1	0	0	5
Lallemant, 2013 [17]	2	–	0	2	2	0	–	0	6
Oysu, 2013 [18]	2	–	1	2	1	0	2	0	8
Park, 2013 [19]	1	–	2	1	2	0	–	0	6
Kayhan, 2014 [20]	1	–	0	2	2	0	–	0	5
Razafindranaly, 2015 [21]	2	0	0	1	2	0	–	0	5
Slama, 2016 [23]	2	0	0	1	1	1	–	0	5
Stubbs, 2018 [24]	2	0	0	1	1	1	–	0	5
Karabulut, 2018 [25]	2	0	0	2	2	1	–	0	7
Doazan, 2018 [26]	2	0	0	1	1	1	0	0	5
Dabas, 2019 [27]	2	–	2	2	1	1	–	0	8
Hans, 2020 [28]	2	0	1	2	2	2	2	0	11
Al-Qurayshi, 2021 [29]	2	–	0	1	1	1	0	0	5
Kaya, 2022 [30]	2	–	2	2	2	0	–	0	8
Papazian, 2023 [31]	2	0	0	1	1	1	0	0	5
Muderis, 2024 [32]	2	–	0	2	2	1	–	0	7

Many studies excluded patients who were lost of follow-up from their analysis, which supports the high results of this item. Abbreviation: –.

influence of the technical characteristics of TORS (3-dimensional view of the surgical field, the 180° amplitude of robot instruments, and 30° optic angulation (easier laryngeal exposure)) as well as the faster TORS learning curve compared to TOLM on the surgical outcomes.

To the best of our knowledge, the present review is the largest systematic review reporting surgical, functional, and oncological outcomes of TORS-SGL. To date, the reviews investigating outcomes of TORS-SGL included 14 [38], 11 [49], and 8 [48] studies, respectively, and focused on some selected surgical, functional, or oncological outcomes. The rapid growth of knowledge through the TORS studies published in the past 5 years can support the update of surgical, functional, and oncological findings, which can facilitate the outcome analysis and comparison with other approaches in further studies. However, as for all systematic reviews including heterogeneous studies, the comparison of data of studies can be biased by the heterogeneity across studies in terms of inclusion criteria, patients, tumor stages, follow-up, and outcomes. Further international consensus in indications and methods of outcome assessment in TORS-SGL can improve the knowledge related to the advantages and inconveniences of TORS-SGL.

Conclusion

The TORS-SGL is a safe, and effective surgical approach for cT1-T3 SGL. The functional and surgical outcomes appear comparable with TOLM-SGL. The oncological outcomes of TORS-SGL could be better than TOLM and open SGL but further large cohort-controlled studies are needed to draw reliable conclusions.

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Declaration of competing interest

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