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Review

Airway and bleeding complications of transoral robotic supraglottic laryngectomy (TORS-SGL): A systematic review and meta-analysis

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Introduction

Since the landmark VA Laryngeal Cancer Study and the RTOG 91–11 trials, non-surgical "organ preservation therapy" for laryngeal cancer has become the standard of care in the United States.[1,2] This treatment paradigm, some feel, is the reason that laryngeal cancer is the only cancer for which there has been a decrease in survival in the past twenty years.[3,4] Specifically, large volume T3 tumors of the larynx have demonstrated a lower survival rate when primary nonsurgical organ preservation therapy is chosen.[4,5] A recent systematic review of treatment outcomes for T3 cancer by treatment type, in fact, demonstrated a lower local control with laryngeal preservation RT as compared to both partial laryngectomy and total laryngectomy.[6]

Thus, conservation laryngeal surgery (CLS) remains an oncologically treatment option – even in this era of chemoradiation. Traditional open supraglottic laryngectomy and supracricoid laryngectomy are still practiced for the carefully selected patient.[7-9] Transoral laser microsurgery (TLM) evolved in the 1980′s and 1990′s as a minimally invasive approach to CLS with both excellent oncologic and functional results.[10] Long-term results have shown 96.8 recurrence-free survival in large single-center studies of open partial laryngectomy.[11] However, for years in the United States, adoption of both open CLS and TLM has lagged behind Europe and the world.

Weinstein, *et al.* first described transoral robotic supraglottic laryngectomy (TORS-SGL) in 2005 in a canine model.[12] In 2009, the first clinical series examining TORS-SGL as proof of concept was published.[13] Since then, many groups have employed TORS-SGL in the treatment of early laryngeal carcinoma and reported results. Recently, Park, *et al.* examined outcomes between patients undergoing traditional open supraglottic laryngectomy and TORS-SGL and found that TORS-SGL is associated with improved functional outcomes and fewer postoperative complications.[14] Yet, in the currently largest published series of TORS, SGL accounts for only 5.85% (24/410) of the total cases, demonstrating its limited use.[15]

Complications and factors associated with complications following TORS-SGL are poorly understood. The goal of this study is to report the rates of bleeding complications associated with TORS-SGL, and to examine management postoperative TORS-SGL hemorrhage. Another objective is to identify any airway complications reported after TORS-SGL, and to examine factors associated with breathing complications as reported in the literature.

Methods

A systematic review of the published literature examining transoral robotic supraglottic laryngectomy was performed according to the Cochrane Handbook for Systematic Reviews of Interventions. A review protocol using the Preferred Reporting of Systematic Reviews and Meta-Analyses (PRISMA-P) and registered (CRD42020203404) was drafted prior to the collection of data.[16] The PICO statement is available in Appendix I. The PubMed, Web of Science, and Cochrane Clinical Trials databases were searched from January 1, 2009 to August 15, 2020 using the MeSH terms "transoral robotic surgery," "robotic surgery," "TORS," "supraglottic laryngectomy," "partial laryngectomy," "laryngectomy," "transoral supraglottic laryngectomy," "transoral partial laryngectomy," "transoral laryngectomy," or a combination of these terms. The exact searches and results are provided in Appendix II. The final search was performed on November 30, 2020. Results were restricted to all articles published in English. Titles and abstracts of all records were screened by authors M.T and W.S for eligibility. Review articles, cadaveric studies, and animal studies were excluded. Articles were also excluded if they were not dedicated to the use of transoral robotic surgery for treatment

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Table 1
Demographics of Included Studies.

Study	Country	Design	LOE	N	Age (Mean)	T1	T2	T3	T4	Concurrent Neck	Delayed Neck	Bil	Uni	TAL (N)	Intraop Trach	LOHS (mean)
Alon	US	Single-institution retrospective series	III	7	61	2	4	1		6	0	3	3		4	5
Ansarin	Italy	Single-institution retrospective series	III	10	68	2	6	2		4	0	4	0		9	13
Dabas	India	Multi-institution retrospective series	III	45	62.9	22	24			46	0	45	0	Y(31)	24	10.3
Doazan	France	Multi-institution retrospective series	III	122	60.8	44	62	16		88	24	17	95		na	na
Hans	Belgium, France	Single-institution retrospective series	III	75	58.2	30	41	5		31	40	40	31	Y(4)	6	6.8
Karabulut	Turkey	Single-institution retrospective series	III	17	62.2	5	4	8		0	17	17	0		0	8.8
Kayhan	Turkey	Single-institution retrospective series	III	13	60	13	0	0		0	13	13	0		0	15.4
Lallemant	France	Single-institution retrospective series	III	10	61.4	4	6	0		10	0	10	0		3	7.5
Mendelsohn	Belgium, France	Single-institution retrospective series	III	18	na	6	10	3		6	3	4	5		0	11
Olsen	US	Single-institution retrospective series	III	9	61.9	1	6	2		9	0	6	3		7	Na
Ozer	US	Single-institution retrospective series	III	13	58.1	1	10	2		12	0	12	0		0	3.9
Park	Korea	Single-institution retrospective series	III	17	65.7	7	6	4		15	0	15	0	Y (14)	17	18.6
Razafindranaly	France	Multi-institution retrospective series	III	84	59	29	46	9		67	0				12	15.1
Stubbs	US	Single-institution retrospective series	III	63	63.6	9	26	10		1	34	36	10		20	5
Total %				Total 503	Mean 61.75	174 34.59%	251 49.90%	62 12.33%	0 0.00%	295 58.65%	131 26.04%	223 44.33%	147 29.22%	49 9.74%	102 20.28%	Mean 9.17

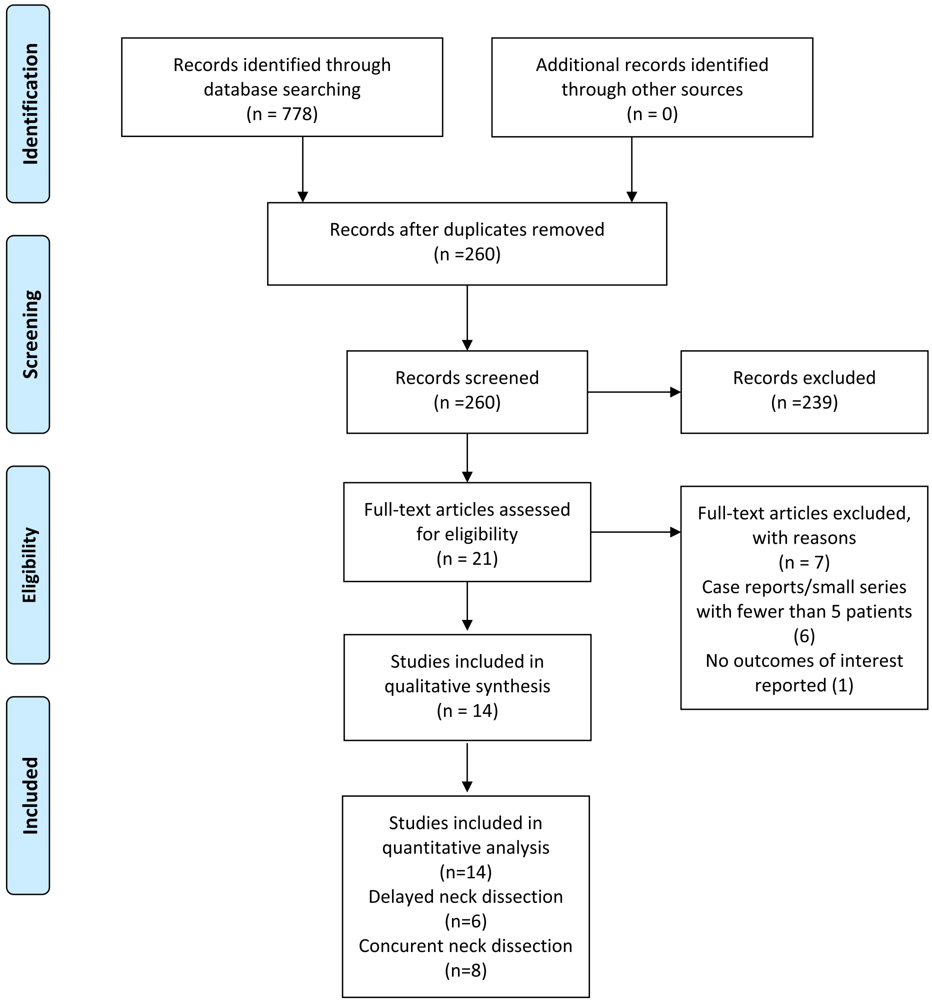


Fig. 1. PRISMA 2009 Flow Diagram.

of supraglottic cancers, were case series with multiple different head and neck cancer sites, or described treatment of pathology other than squamous cell carcinoma. Full text articles were reviewed for eligibility prior to inclusion in the final qualitative analysis. This led to the exclusion of additional case reports, case series that included fewer than five patients, and series that did not report bleeding and/or airway complications.

Data extraction was performed by the two primary authors (M.T. and W.S.). Data extracted from individual studies included: the country of origin, the study design, the total number of patients, the mean age of patients, the number of tumors by tumor stage, the number of unilateral vs. bilateral neck dissections, the number of concurrent vs. delayed neck dissections, and the mean length of hospital stay (LOHS) in days. Extraction of data with respect to bleeding complications included the total number bleeding events, deaths due to hemorrhage, major bleeding events (defined as those requiring surgical intervention), minor bleeding events (those medically managed with transfusion or observation), the type of operative intervention (*i.e.*, transoral control of hemorrhage with cautery, transoral control of hemorrhage with clips, transcervical arterial ligation (TAL), emergent tracheostomy, or embolization), the method of control of hemorrhage (clips vs. cauterization), timing of postoperative hemorrhage, and the use of TAL to prevent hemorrhage. Extraction of data with respect to airway complications included the total number of patients, the number of elective perioperative tracheostomies (those performed during the same operation as TORS), the number of postoperative tracheostomies (unplanned tracheostomies in a separate operation after TORS), the number of permanent tracheostomies, the number of patients immediately extubated, the number of patients who were kept intubated in the postoperative period, the total number of airway complications, the number of deaths due to airway complications, the number of aspiration pneumonias, the number of patients developing laryngeal stenosis, the number of concurrent neck dissections performed, and the number of delayed neck dissections performed.

Study bias assessment was conducted on each study included in the final analysis by three authors (M.T., W.S. and S.H) using the National Institutes of Health Quality Assessment Tool for case series studies.[17] The NOS judges studies based upon three broad categories: 1) the selection of the study group; 2) comparability of the groups; and 3) ascertainment of the outcomes of interest. The highest quality studies receive nine stars. See Appendix III. Disagreements about bias assessment were resolved through reassessment and virtual conference discussion for the development of a consensus on the level of bias. Studies were also assessed for the level of evidence presented based on guidelines written by the Center for Evidence-Based Medicine.[18] See Table 1.

The primary outcomes were overall postoperative hemorrhage and airway complication rates. Secondary outcomes were major postoperative bleeding, minor postoperative hemorrhage, aspiration pneumonia rates, perioperative tracheostomy, and unplanned postoperative tracheostomy rates. For this study, major postoperative hemorrhage was defined as postoperative bleeding requiring operative intervention with transoral ligation of a named vessel, intravascular embolization, tracheostomy for airway control, or TAL within 30 days of surgery. Minor postoperative hemorrhage was defined as postoperative bleeding in which patients reported bleeding, presented to the emergency room, or were admitted to the hospital within 30 days of surgery. TAL was defined as ligation of any branch of the external carotid artery during neck dissection or postoperatively in the neck. Additional subgroup analysis was performed to look at factors impacting bleeding or airway complications. For bleeding complications, the authors examined any mention of prophylactic TAL or perioperative anticoagulant/antiplatelet therapy. Tertiary outcomes were death due to hemorrhage, post-operative intubation, permanent tracheostomy rates, and airway complications requiring postoperative surgical intervention. Finally, the authors examined subgroups that compared prior institutional experience with transoral laser partial laryngeal surgery experience with supraglottic laryngectomy, perioperative tracheostomy use, and delayed neck dissection as an institutional practice to see if there was any effect on rates of bleeding or breathing complications.

Statistical analysis was performed using the *meta*-analysis package for R, "metaphor".[19] Rates of bleeding and airway compromise were calculated. Meta-analysis of incidence rates of these events was performed using the inverse variance method with the Freeman-Tukey double-arcsine transformation due to a large number of studies with zero events.[20] A back-transformation was performed using the harmonic mean of the sample size across all studies.[21] Assessment of significant heterogeneity across studies was examined using the chi-squared statistic and Fisher's exact test. The I^2 statistic was also used to measure the heterogeneity between study results.[22] Proportional *meta*-analysis was performed using a random effects model.

Results

Study selection and bias assessment

A total of 260 studies were identified according to the search criteria, of which 14 studies including 503 patients were included in the final qualitative analysis. The overall study selection process is detailed in the PRISMA flow chart shown in Figure 1. Table 1 presents the individual details of those studies selected for inclusion in this systematic review. The majority of studies were published by groups in the United States (4), Belgium (2), and France (2). Two studies were multi-institutional, while the remaining 12 were single-institution studies performed in tertiary care centers. All included studies represent Level III evidence. Appendix III presents the results of our bias assessment. The quality of most studies (92%) was good with respect to reporting and managing complications.

Study demographics

A total of 503 patients underwent TORS-SGL for the treatment of squamous cell carcinoma of the supraglottic larynx. The mean age of these patients was 61.75 years. Most patients had T2 tumors (49.90%), followed by T1 (34.59%) and T3 (12.33%) tumors. No T4 tumors were treated by TORS-SGL. Two hundred ninety-five patients (58.65%) underwent concurrent neck dissection, while 131 patients (26.04%) underwent delayed neck dissections. Two hundred twenty-three patients (44.33%) required bilateral neck dissections, while 174 (29.22%) were treated with unilateral, ipsilateral neck dissection. One hundred two patients (20.28%) were treated with elective intraoperative tracheostomy according to surgeon preference to prevent airway complications and/or airway compromise due to hemorrhage. The overall mean LOHS for patients undergoing TORS-SGL was 9.17 days (range: 3.9 to 18.6 days).

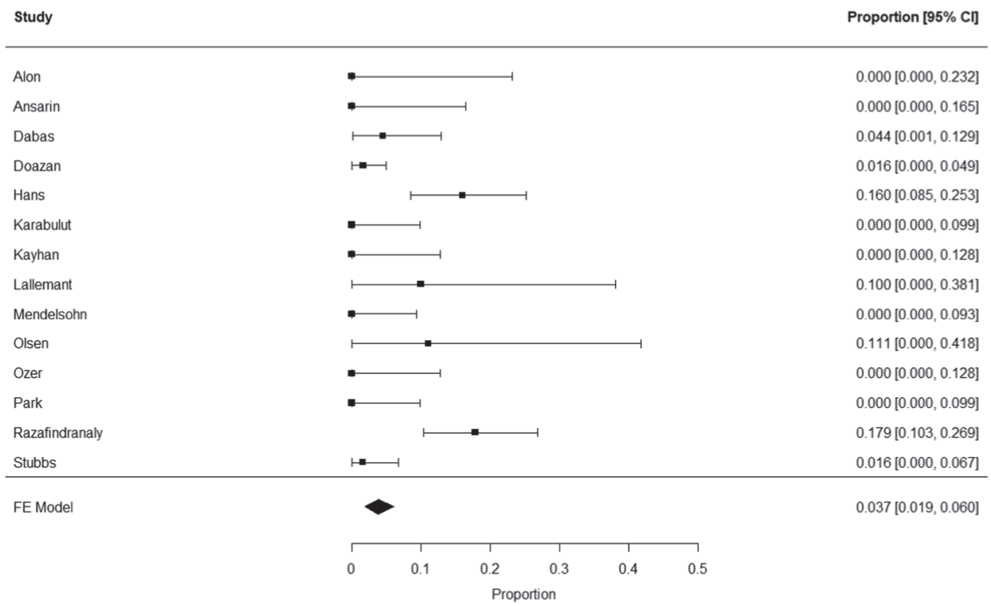
Perioperative management of bleeding

Seven studies specifically discussed intraoperative methods of hemostasis during TORS-SGL.[14,23-28] All seven studies, which included

Table 2
Bleeding complications of TORS-SGL.

Study	N	Events	Major	Minor	Operative control	Elective trach due to intraop bleeding	Elective trach rate	Emergent Trach	Emergent TAL	Embolization	Death d/t POH	Concurrent Neck	TAL	Intraop Hemostasis	PODH
Alon	7	0	0	0	0	4	57.14%					6		clips	
Ansarin	10	0	0	0	0	9	90.00%	0		0	0	4			
Dabas	45	2	2	0	2	24	53.33%			0	0	45	31	clips and ligation	
Doazan	122	2	2	0	2						2	88			14, 14
Hans	75	12	4	8	4	6	8.00%					71	4	clips and ligation	10
Karabulut	17	0	0	0	0	0		0		0	0	0			
Kayhan	13	0	0	0	0	0		0	0	0	0	0	0		
Lallemant	10	1	1	0	1	3	30.00%	1	0	0	0	10	0		2
Mendelsohn	18	0	0	0	0	0						6			
Olsen	9	0	0	0	1	7	77.78%	0	1	0	0	9		clips	
Ozer	13	0	0	0	0	0		0		0	0	12			
Park	17	0	0	0	0	17	100.00%	0		0	0	15	14	clips and ligation	
Razafindranaly	84	15	12	3	12	12	14.29%	0		0	1	67		Clips	
Stubbs	63	1	1	0	1	20	31.75%	1	1	0	0	1		clips	13
Total	**503**	**33**	**22**	**11**	**23**	**102**		**2**	**2**	**0**	**3**	**294**	**49**	**Clips = 7 studies**	
	257	**6.56%**	**4.37%**	**2.17%**	**4.55%**	**20.28%**	**51.37%**	**0.40%**	**0.40%**	**0%**	**0.60%**	**58.45%**	**9.74%**	**Ligation = 2 studies**	**10.6**

*TAL indicated transcervical artery ligation.
*POH indicates post-operative haemorrhage.
*PODH indicates post-operative day of haemorrhage.



I^2=64.01%

Fig. 2. Forest Plot of Overall Bleeding Rates after TORS-SGL.

268 patients, employed transoral endoscopic clip appliers to ligate the internal branch of the superior laryngeal artery laterally near its entrance at the thyrohyoid membrane. Three studies reported the use of prophylactic TAL during concurrent neck dissection in addition to transoral clipping.[14,24,29]. In those three studies, TAL was performed on 49 of 137 total patients. Dabas, *et al.* performed TAL on 31 of 45 patients.[24] Park, *et al.* performed TAL of the superior laryngeal artery on 14 of 17 patients during concurrent neck dissection prior to TORS-SGL.[14] Hans, *et al.* performed prophylactic TAL in 4 of 75 patients due to severe intraoperative hemorrhage from the internal branch of the superior laryngeal artery.[29] Overall, prophylactic TAL during concurrent neck dissection has only been performed in 9.74% of the TORS-SGL reported in the literature and seems to be largely due to institutional practice or surgeon preference. Few studies mentioned the use of prophylactic tracheostomy for the management of postoperative hemorrhage. Ansarin, *et al.* performed tracheostomy on patients deemed to be high-risk for postoperative hemorrhage – *i.e.*, those on anticoagulation or those with intraoperative blood loss of more than 300 ml.[30]

Bleeding complications

There is a large variance in reported hemorrhage rates across the studies reviewed, with a range of zero to 17.86%. In total, thirty-three patients experienced postoperative hemorrhage. Data on bleeding complications is presented in Table 2. The overall rate of postoperative hemorrhage according to this *meta*-analysis is 3.74% [95% CI = 1.89%-6.02%](Figure 2). Minor hemorrhages accounted for 11 (33.33%) events.[25,27] Twenty-two patients required some sort of operative intervention for control of hemorrhage and thus were considered major hemorrhages.[24,25,27,28,31,32] The overall minor and major hemorrhage rates from this *meta*-analysis following TORS-SGL were 0.15% (95% CI = 0–1.15%) (Figure 3A) and 2.28% (95% CI = 0.80–4.24%), respectively (Figure 3B).

Major postoperative hemorrhage was most often managed by transoral clipping or coagulation of the internal branch of the superior laryngeal artery, which was specifically mentioned in three studies.[25,27,32]. The day of postoperative hemorrhage was reported in five studies and occurred on average around postoperative day (POD) 10 (range: POD2-14).[25,28,31,32] Two of the three deaths due to massive postoperative hemorrhage occurred on POD 14.[31] Two patients (0.40%) underwent emergent tracheostomy to control the airway during postoperative hemorrhage, which occurred on POD2 and POD13.[28,32] No patient underwent emergent embolization or TAL for the treatment of postoperative hemorrhage. Three patients died (0.60%) due to cardiopulmonary complications associated with postoperative hemorrhage.[27,31]

Three studies attempted to identify factors associated with postoperative hemorrhage[24,25,27] Razafindranaly, *et al.* attempted to identify risk factors for hemorrhage but found none in that data.[33] Hans, *et al.* found that six of 12 patients experiencing postoperative hemorrhage had been on aspirin in the postoperative period, the only risk factor identified.[29] Dabas, *et al.* attempted to analyze the effect of TAL on postoperative hemorrhage rates and found no difference.[24] Of the two postoperative bleeding events in that study, one occurred in a patient who had undergone TAL and the other occurred in a patient who had not. Pooling extractable data from the two studies that used ligations vs. clips, the bleeding rate among the ligated patients was 2.22% (1/45) and the bleeding rate among those who were clipped was 5.88% (1/17).[14,24]

Perioperative airway management

Thirteen of 14 studies discussed perioperative airway management following TORS-SGL. Only Doazan, *et al.*, neglected to discuss perioperative airway management.[31] The rate of perioperative tracheostomy use in the literature study was 20.28%. Only Park, *et al.* routinely performed tracheotomy on all patients during that study period to improve visualization of the tumor during dissection and to prevent devastating complications from airway obstruction or bleeding.[14] Eight studies reported on the use of prophylactic tracheostomy during TORS-SGL to manage the airway. In those studies, 103 of a total 303 patients had tracheostomy tubes placed. Of those performing prophylactic tracheostomy for airway management, three did so because of bilateral neck dissection as a risk factor for obstruction[14,23,30], three did so because of risk for postoperative hemorrhage[14,25,30], one did so for large resections at the discretion of the operating surgeon[32], one did so for patients deemed high-risk for aspiration or difficult intubation due to trismus[24], and the last did so for patients with a high-risk of

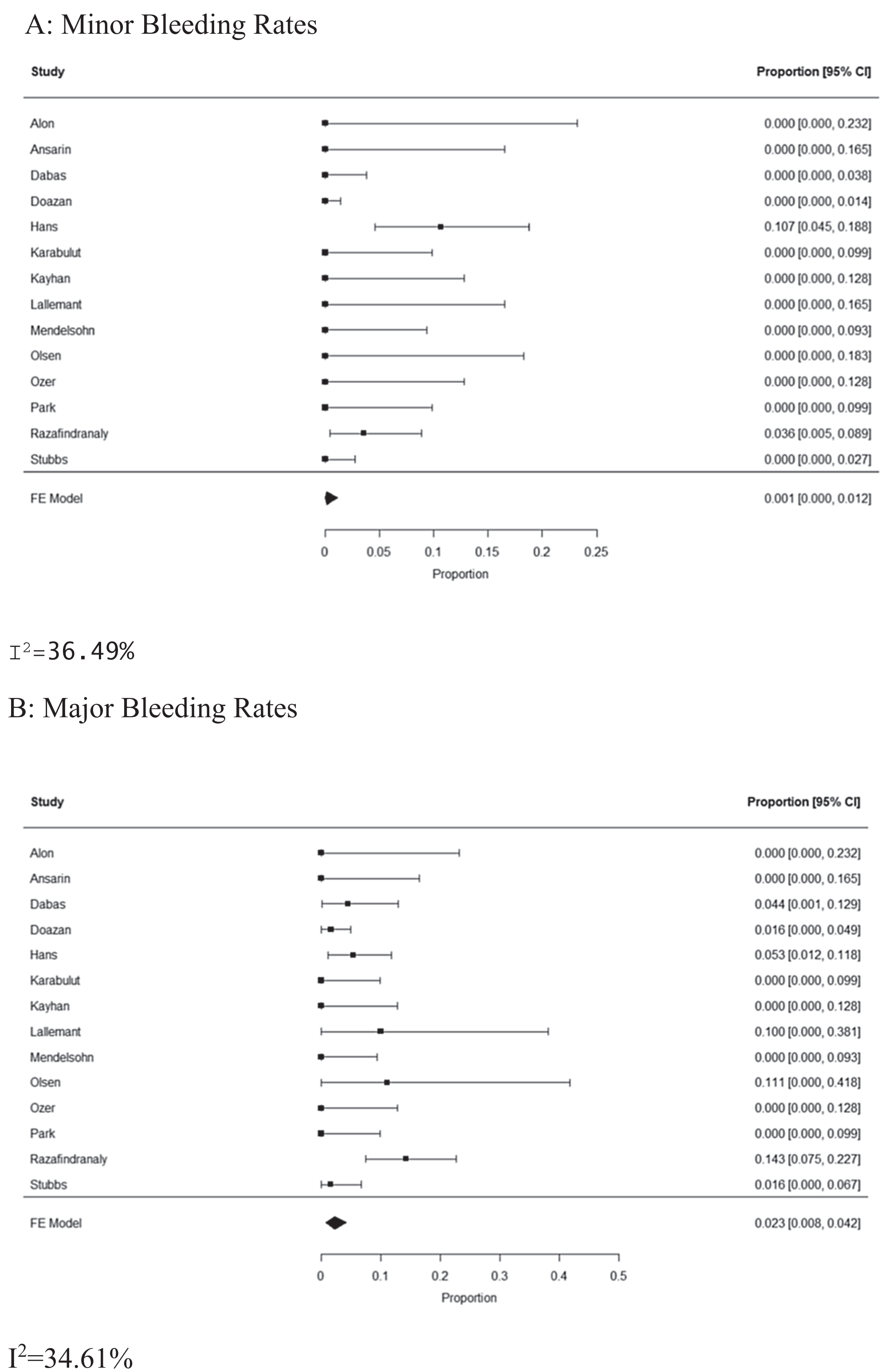


Fig. 3. Forest Plot of Minor and Major Bleeding Rates following TORS-SGL.

postoperative edema or airway obstruction.[14,27] Of the four studies that did not use perioperative tracheostomy for airway management, two reported routine use of temporary postoperative intubation for a period of 24–36 h.[34,35]. Only Ozer, *et al.* reported immediate extubation without perioperative tracheostomy use for all patients.[36]

Some institutions with a background in transoral laser surgery for laryngeal cancer hypothesized that concurrent bilateral neck dissection is a risk factor for postoperative laryngeal edema and therefore only performed neck dissections in delayed fashion (several weeks after TORS-SGL) in order to prevent immediate postoperative airway edema and decrease the need for perioperative tracheostomy.[25,28,34,35,37] The groups that performed concurrent neck dissection would also perform perioperative tracheostomy on certain patients to prevent airway compromise due to postoperative laryngeal edema.[14,23-28,30,32] Among these, only one group performed routine concurrent neck dissections with TORS-SGL, Park, *et al.*, performed routine

Table 3
Airway Complications of TORS-SGL.

Study	N	Death	Events	PNA/ Aspiration	Postop Intubation	Elective Trach	Emergent Trach	Permanent Trach	Laryngeal Stenosis	Concurrent neck	Delayed Neck	Prior Neck	No neck dissection
Alon	7		2	1		4	1	1	1	6	0	1	1
Ansarin	10		3	2		9			0	4	0	0	6
Dabas	45		2	2		24	0	3	0	45	0	0	0
Doazan	122	1*	5	3					0	88	24	0	10
Hans	75		3	3		6	0	0	0	31	40	0	2
Karabulut	17		2	1		0	0	0	1	0	17	0	0
Kayhan	13		3	2	24–36 h	0	3	0	1	0	13	0	0
lallemant	10		0	0		3	0	0	0	10	0	0	0
Mendelsohn	18			0	24 h	0	0	0		6	3	0	9
Olsen	9		1			7	0	2	1	9	0	0	0
Ozer	13		1	0	Immediate extubation	0	1	0	0	12	0	1	0
Park	17		1	0		17	0	0	1	15	0	0	2
Raza	84		19	19		12	8	1	0	67	0	0	17
Stubbs	63					20	4		0	1	47	15	0
Total	**503**	1*	**42**	**33**		**102**	**17**	**7**	**5**	**294**	**144**	**17**	**47**
			8.35%	**6.56%**		**20.28%**	**3.38%**	**1.39%**	**0.99%**	**58.45%**	**28.63%**	**3.38%**	**9.34%**

* PNA/Aspiration indicates post-operative pneumonia or aspiration events.

prophylactic tracheostomy in all patients as a means to prevent postoperative airway compromise.[14] This study demonstrates that delayed neck dissection was associated with a significantly decreased risk of perioperative tracheostomy compared to concurrent neck dissection, 13.98% vs. 33.15%. However, this was driven by a surgeon's preference for elective tracheostomy. Overall, the rate of unplanned postoperative tracheostomy with delayed vs. concurrent neck dissection was 3.76% vs. 5.62%, though the difference in rates was not statically significant.

Airway complications

Airway complications were reported in 42 of 503 patients undergoing TORS-SGL (Table 3). Using incidence-based *meta*-analysis the event rate of postoperative airway complications across included studies was 4.92% (95% CI = 2.83%-7.40%) (Figure 4). The most common complication was postoperative aspiration pneumonia, which occurred in a total of 33 patients (6.56%). Other complications included: emergent postoperative tracheostomy tube placement for the treatment of airway compromise in 17 patients (3.38%), tracheostomy tube dependence in seven patients (1.39%), laryngeal stenosis requiring intervention in five patients (0.99%) and pulmonary embolism in one patient (0.002%) that resulted in death. All four patients with stenosis required surgery to treat it, and most (80%) required tracheostomy.[14,23,26,35] One study reported the rate of temporary postoperative vocal fold immobility, which was seen in five of 18 patients (27.78%) and lasted for a median duration of 24 days.[34]

Only five studies reported on postoperative tracheostomy use in the management of airway complications. In those studies, 17 of a total 180 patients required a postoperative tracheostomy due to postoperative airway compromise.[23,27,28,35,36] In this study, the relative risk of postoperative tracheostomy in patients who underwent neck dissections was examined, and there was no difference in the relative risk between those undergoing delayed vs. concurrent neck dissection (RR = 0.5206, 95%CI = 0.2041–1.3279), p = 0.1718.

Factors associated with airway complications have not been thoroughly studied. In fact, only one study by Stubbs, *et al.* reports on risk factors for elective perioperative tracheostomy.[28] In that study, tumors involving more than one subsite presented a significantly higher risk of tracheostomy (85% vs. 54%), p = 0.031. Similarly those patients treated with delayed neck dissections were less likely to require perioperative tracheostomy than those patients treated with concurrent neck dissection, 82.8% vs. 58.8%, p = 0.073. In the present study, delayed neck dissection was associated with a significantly lower risk of perioperative tracheostomy tube use, 13.98% vs. 33.15% (RR = 0.4217, 95%CI = 0.2790–0.6374), p = 0.0001. In examining the methods of the included studies, this is largely the result of surgeon preference and theoretic risk of laryngeal lymphedema as a sequela of bilateral concurrent neck dissection. It should also be emphasized that two of the three studies that did not use elective perioperative tracheostomy left patients intubated for a period of 24–36 h.[34-36]

Discussion

TORS-SGL is a relatively novel surgical technique for the treatment of early supraglottic laryngeal carcinoma. So far only 14 groups have reported on their experience with the procedure, with a relatively small number of cases (503 patients) having been reported in the literature to date. Other groups have provided case reports or small case series involving fewer than five patients.[13,38-42] Of those groups performing this procedure, several have prior institutional knowledge of transoral supraglottic laryngectomy using transoral laser microsurgery.[25,26,34]

Oncologic and functional outcomes of TORS-SGL have been studied over the past 10 years. A recent systematic review by LeChien, *et al.* studied outcomes after TORS-SGL and reported two-year and five-year

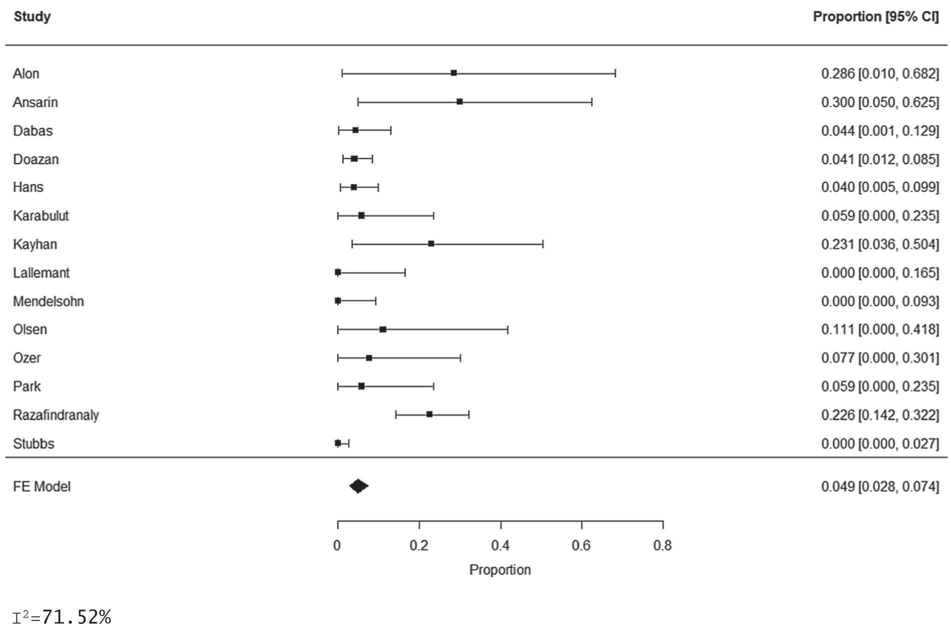


Fig. 4. Forest Plot of Overall Airway Complications Rates following TORS-SGL.

local control rates (LCR) ranging from 93.4 to 100% and 90.2–93.2%, respectively.[43] Two-year disease-free survival (DFS) rates ranged from 91.0 to 95.1%. In all of the literature, only one group has reported a five-year DFS, which was 94.3%.[25] In that review, tracheostomy was performed in 27.3% of patients, while percutaneous endoscopic gastrostomy was used in 8.82%. While Lechien, et al. listed the reported complications after TORS-SGL, the study did not exam the details of bleeding or airway complications, nor the management of those complications.

This is the first systematic review dedicated to studying the complications of TORS-SGL. In it we address bleeding complications and identify an overall postoperative hemorrhage rate of 3%, with the mean time to hemorrhage on POD10. While the overall hemorrhage rate is lower following TORS-SGL compared to TORS in the treatment of oropharyngeal cancer, the major hemorrhage rates (2.28%) and timing of postoperative hemorrhage (median 8 days) were similar to those reported for TORS in the treatment of oropharyngeal cancer.[44](Stokes *et al.*). Specifically, overall hemorrhage rates appear to be lower for TORS-SGL (3.74%) vs. conventional TORS (5.78%). Similarly, minor hemorrhages are lower for TORS-SGL (0.15%) vs. conventional TORS (5.29%). This is likely because there is little surface area and less vascularity in the TORS-SGL defect which is comprised of the paraglottic and pre-epiglottic fat as compared to the sometimes large, granulating wound in the highly vascular parapharyngeal space and base of tongue musculature after TORS oropharyngectomy and/or base of tongue resection. TAL, therefore, may not be a critical to reducing hemorrhage in TORS-SGL as it is in TORS oropharyngectomy.

TAL has been associated with a clinically important reduction in the rate of major postoperative hemorrhage events of the oropharynx and has become a standard practice to prevent major hemorrhage in clinical trials such as ECOG 3311(NCT01898494).[44-46] This practice, however, is not standard in TORS-SGL, which has overall major and minor hemorrhage rates of 2.28% and 0.15%. As demonstrated by this review, the use of TAL was only reported in three series and performed on a total of 49 patients undergoing TORS-SGL (9.74%) in the literature. This difference in practice might best understood in terms of the difference in blood supply and general vascularity between the oropharynx and the larynx. Van Abel and Moore described the vasculature to the oropharynx in detail and note that the variable contribution of the lingual and facial arteries to the blood supply as well as their tortuosity in the base of tongue make control of hemorrhage more challenging both intraoperatively and postoperatively.[47] The blood supply to the larynx, however, is limited to the two internal branches of the superior laryngeal nerve whose entry into the larynx is at a singular fixed point allowing for more reliable control with transoral clips. Using a post-hoc sample size calculator and the estimated bleeding rates in studies using clips vs. TAL, a study with a total of 576 patients with 288 patients in each group would be needed to detect a meaningful difference in bleeding rates. Even so, the need for ligation may not be significant as successful identification and transoral ligation with clips may and might be related to the learning curve associated with TORS-SGL.

Management of hemorrhage following TORS-SGL is slightly different compared to TORS oropharyngectomy. Emergent tracheotomy and TAL rates are similar given the relatively few patients and few events. However, given the very predictable blood supply of the larynx, most hemorrhages are controlled with transoral clipping or cautery of the internal branch of the superior laryngeal artery. Embolization, therefore, is rarely required and has not been reported as a method of controlling hemorrhage after TORS-SGL. This differs from the management of hemorrhage after TORS for oropharyngeal cancer, where embolization was the preferred method of control in 22 patients (0.38%).

Airway complications following TORS-SGL have not yet been well studied. The best information to date comes from a University of Pennsylvania series on 63 patients over a ten-year period undergoing TORS-SGL.[28] In that study by Stubbs *et al.*, 32% of patients required elective tracheostomy at the time of surgery, with only four patients (6.35%) undergoing unplanned postoperative tracheostomy.[48] Only one of those patients had a postoperative hemorrhage event requiring emergent tracheostomy for airway obstruction and another for airway control during hemorrhage. The authors also noted a reduction in the use of tracheostomy with experience and suggested from their findings that tumors involving more than one subsite are better served with temporary tracheostomy. No other studies have examined the use of tracheostomy and risk factors for postoperative tracheostomy specifically. From this review of the literature, it is clear that the use of prophylactic perioperative tracheotomy is therefore largely dependent on surgeon experience and/or preference.

Concurrent neck dissection along with open supraglottic laryngectomy has not traditionally led to higher complication rates or been associated with duration of tracheostomy.[49] However, when performing supraglottic laryngectomy with transoral laser microsurgery , authors have tried to eliminate the use of temporary tracheostomy and cited bilateral concurrent neck dissection as a potential cause of laryngeal lymphedema and postoperative airway obstruction.[26,34,48] In this study, perioperative tracheostomy use was largely linked to surgeon preference and was significantly associated with performance of concurrent bilateral neck dissection ($p = 0.0001$). Given the relative novelty of this surgery, extreme caution has been applied with regard to preventing postoperative airway complications. With increased experience, this may change slightly as suggested by Stubbs et al.[48]

This study has several limitations. First, there is most certainly selection bias in favor of smaller, surgically favorable tumors in these series, leading to a likely underestimation of complications with broader application of TORS-SGL. Second, small surgical series, such as those included, are subject to are likely to underestimate the incidence of rare or catastrophic complications not encountered reliably without larger sample sizes. Finally, authors are less likely to publish a series with high complication rates and may cease to perform certain operations or continue to study them in the face of serious complications. In the face of these limitations, this study presents the best available data to date on complications after TORS-SGL and their management. Further, the authors consider this review important as it pools the existing data so that those interested in expanding their TORS practice to include TORS-SGL might understand complications and their management.

Conclusions

The pooled incidence rates of bleeding and airway complications following TORS-SGL are 3.74% and 4.92%, respectively. The perioperative death rate due to these complications is 0.60%. Perioperative tracheostomy has been proposed to prevent catastrophic events resulting from hemorrhage and airway complications in subsets of patients at high risk for postoperative airway edema (those with multiple subsites and those treated with concurrent bilateral neck dissections) and is used about 20.28% of the time. Those groups performing delayed neck dissections had a significantly lower risk of perioperative tracheostomy placement ($p =< 0.0001$).

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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Appendix I. PICO statement

Population: Adult patient over 18 with Squamous cell carcinoma of the larynx undergoing transoral robotic supraglottic laryngectomy as definitive treatment.

Interventions:

1) Transoral robotic supraglottic laryngectomy with transcervical arterial ligation
2) Transoral robotic supraglottic laryngectomy with tracheostomy
3) Transoral robotic supraglottic laryngectomy with concurrent neck dissection

Comparison:

1) Transoral robotic supraglottic laryngectomy without transcervical arterial ligation
2) Transoral robotic supraglottic laryngectomy without tracheostomy
3) Transoral robotic supraglottic laryngectomy without concurrent neck dissection

Outcomes:
Primary outcomes:

1) total bleeding events, major bleeding (requiring operative intervention), minor bleeding events (those being observed, requiring admission, or transfusion), death due to bleeding,
2) airway events, airway events require postoperative tracheostomy, death due to airway compromise

Secondary:

1) minor bleeding (medically managed), bleeding requiring tracheostomy, bleeding requiring embolization, bleeding requiring reoperation, management of hemorrhage (clips, neck dissection, embolization, cautery), concurrent neck dissection, delayed neck dissection
2) aspiration, pneumonia, postoperative tracheostomy, permanent tracheostomy, development of laryngeal stenosis, treatment of laryngeal stenosis, concurrent neck dissection (theoretically increased postoperative edema risks), delayed neck dissection (theoretically lowers postoperative edema risk.)

Appendix II. MeSH search terms and results

PubMed Results w endnote for MTT
“TORS” + “supraglottic laryngectomy” = 30
“TORS” + “laryngectomy” = 48
“TORS” + “partial laryngectomy” = 17

"Transoral robotic surgery" + "supraglottic laryngectomy" = 53
"Transoral robotic surgery" + "laryngectomy" = 87
"Transoral robotic surgery" + "partial laryngectomy" = 33
"Transoral supraglottic laryngectomy" = 110
"Transoral partial laryngectomy" = 136
"Transoral laryngectomy" = 332
"Robotic surgery" + "supraglottic laryngectomy" = 53
"Robotic surgery" + "laryngectomy" = 96
"Robotic surgery" + "partial laryngectomy" = 34
Total = 778, After removal duplicates – 263, 2009 to present: 263, In English only: 206, After screening titles and abstracts: 21, Included in Final analysis: 14
Web of Science Results for MTT
"TORS" + "supraglottic laryngectomy" = 37
"TORS" + "laryngectomy" = 79
"TORS" + "partial laryngectomy" = 18
"Transoral robotic surgery" + "supraglottic laryngectomy" = 46
"Transoral robotic surgery" + "laryngectomy" = 107
"Transoral robotic surgery" + "partial laryngectomy" = 31
"Transoral supraglottic laryngectomy" = 4
"Transoral partial laryngectomy" = 0
"Transoral laryngectomy" = 2
"Robotic surgery" + "supraglottic laryngectomy" = 49
"Robotic surgery" + "laryngectomy" = 120
"Robotic surgery" + "partial laryngectomy" =34
Total 128, Added to endnote from above − 50 duplicates, 78 added. New Total: 284
Cochrane Results for MTT
"TORS" + "supraglottic laryngectomy" = 0
"TORS" + "laryngectomy" = 0
"TORS" + "partial laryngectomy" = 0
"Transoral robotic surgery" + "supraglottic laryngectomy" = 0
"Transoral robotic surgery" + "laryngectomy" = 1 (Meulemans) - included
"Transoral robotic surgery" + "partial laryngectomy" = 0
"Transoral supraglottic laryngectomy" =
"Transoral partial laryngectomy" = 1 not relevant
"Transoral laryngectomy" = 7 none relevant
"Robotic surgery" + "supraglottic laryngectomy" = 0
"Robotic surgery" + "laryngectomy" = 0
"Robotic surgery" + "partial laryngectomy" = 0
Total remains 284, After screening abstract and title: 37, After full text review: 14

Appendix III. Bias assessment of included studies

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Quality
Alon	Y	Y	NR	Y	Y	Y	Y	NA	Y	GOOD
Ansarin	Y	Y	Y	Y	Y	Y	Y	NA	Y	GOOD
Dabas	Y	Y	Y	Y	Y	Y	Y	NR	Y	GOOD
Doazan	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Hans	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Karabulut	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Kayhan	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Lallemant	Y	Y	Y	Y	Y	Y	Y	N	Y	GOOD
Mendelsohn	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Olsen	Y	Y	Y	Y	Y	Y	N (12 months)	Y	Y	GOOD
Ozer	Y	Y	Y	Y	Y	Y	N (6.8 months)	Y	Y	GOOD
Park	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Razafindranaly	Y	Y	CD*	Y	Y	Y	N (14 months)	Y	NA**	FAIR
Stubbs	Y	Y	Y	Y	Y	Y	Y	Y	Y	GOOD
Total Y (Yes)	100%	100%	0.85714286	100%	100%	100%	0.78571429	0.71428571	0.92857143	

Y = Yes, N = No, CD = Cannot determine, NR = not reported, NA = Not application.

Good	100% for complications
Fair	92% for complications and results given
*	Razafindranaly, *et al*, performed a multi-institutional study and cases were reviewed retrospectively. It is unclear if patient's were consecutively enrolled if they met inclusion criteria or whether or not there was exclusion for comorbidities.
**	Razafindranaly, *et a*l, did not describe breathing outcomes or tracheostomy use intraoperatively

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