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The Role of Soft-tissue Surgery of the Tongue in OSA

J. Beyers MSc[a], O.M. Vanderveken MD, PhD[a,b], P.H. Van de Heyning MD, PhD[a,b], Hamans E MD, PhD[a,b,*]

[a]Department of Otorhinolaryngology, Head and Neck Surgery, University Hospital Antwerp, Edegem, Belgium
[b]Faculty of Medicine and Health Sciences, University of Antwerp, Antwerp, Belgium
* Corresponding author at: Antwerp University Hospital (UZA), Wilrijkstraat 10, 2650 Edegem, Antwerp, Belgium. Tel.: +32 (0)3 821 33 85; E-mail address: evert.hamans@uza.be (E. Hamans).

Abstract Obstructive sleep apnoea is a common disease with high morbidity. Narrowing and collapse of the pharyngeal airway during sleep characterize the disease resulting in a decrease or a complete cessation of oronasal airflow. Continuous positive airway pressure (CPAP) is the gold standard and is proven to be very effective. However, due to its rather low adherence and acceptance, alternative treatment options for OSA are necessary. When obstruction of the upper airway (UA) is caused at the level of the tongue base, surgery of the soft-tissue of the tongue may be an effective treatment option in OSA. In this review, the aim is to determine and compare the effect of glossectomy, transoral robotic surgery (TORS), radiofrequency (RF), tongue suspension and adjustable tongue advancement techniques in terms of efficacy based on changes in outcome parameters and in terms of complications. UA surgery significantly improves sleep outcomes as part of multilevel surgery in adult patients. Further research on the efficacy of standalone procedure of soft-tissue surgery techniques of the tongue is necessary, in order to gain more evidence of their effectiveness.

Keywords OSA, soft-tissue surgery, tongue reduction, tongue advancement, tongue suspension

Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent episodes of upper airway (UA) obstruction during sleep resulting in a decrease or a complete cessation of oronasal airflow. Collapse can occur at different levels in the UA. OSA affects millions of people worldwide and can be life threatening. The disorder leads to irregular breathing and snoring, daytime sleepiness, hypertension, cardiovascular disease, stroke, motor vehicle accidents, and diminished quality of life [1, 2].

The treatment of OSA is dependent on the severity of the disease, upper airway anatomy and the preference of the patients. Continuous positive airway pressure (CPAP), which allows the patients to breathe by pushing the walls of the pharynx apart, is the gold standard treatment for patients with OSA [3]. When CPAP treatment is successful, a reduction in the frequency of respiratory events during sleep can be seen. However, poor adherence and acceptance issues of CPAP can lead to less potential benefits of the therapy [4]. In these patients, other treatment options such as oral appliances, a variety of surgical approaches and nervus hypoglossus stimulation, need to be considered [5, 6]. Uvulopalatopharyngoplasty (UPPP), which is the most frequently performed surgical techniques as an alternative treatment option in OSA, fails when the obstruction of the airway is caused by collapse of the tongue base. The tongue base is involved in sleep-disordered breathing in up to 46.6 % of the cases in mild to moderate OSA as part of multilevel collapse. In 9.4% of the cases the tongue base is causing single level collapse [7]. For patients with clinical signs of tongue base obstruction and without typical findings at the soft palate, tongue base surgery may be beneficial. A number of surgical procedures to address the area of the tongue base have been developed in the past years. Besides, tongue base surgery may be part of multi-level surgical approaches in patients with multilevel collapse. Selection of the correct surgical procedure is crucial for the outcome of the treatment. Thus, examination of the UA in order to determine the anatomical and physiological site of obstruction is needed when surgery is considered as treatment in OSA.

The aim of this article is to review recently published data on soft-tissue surgery of the tongue for the treatment of OSA, based on the changes in main outcomes such as apnea-hypopnea index (AHI), Epworth Sleepiness Scale (ESS), and in terms of observed complications after surgery.

Material and Methods

Literature Search

PubMed-NCBI database was used to perform a comprehensive literature search. Following search terms were used: (1) glossectomy AND "sleep apnea", (2) TORS AND "sleep apnea", (3) tongue base radiofrequency AND "sleep apnea", (4) tongue suspension AND "sleep apnea", (5) adjustable tongue advancement AND "sleep apnea". Only articles in English were included in the search. Screening of the relevance of the articles for this review occurred according to title and abstract. The reference lists of the articles used for this review were also screened for additional studies. The search strategy is explained in detail in figure 1. The literature search resulted in the inclusion of 51 articles. Two of the articles were used in the discussion of the radiofrequency technique as well as in the discussion of the tongue suspension approach [8, 9].

Tongue reduction

Partial glossectomy

When OSA is primarily related to hypertrophy of the tongue base, partial glossectomy may improve OSA. Removal of a midline portion of the tongue base and excess tissue enlarges the hypopharyngeal airway [10].

In the past, this surgery was performed using the surgical laser technique but nowadays, other surgical techniques such as the use of irrigating, suctioning bipolar devices using coblation are preferable [11-13]. Various techniques of partial glossectomy for OSA are available, such as midline glossectomy, submucosal minimally invasive lingual excision and lingualplasty.

Murphey et al. recently reviewed the effect of glossectomy for OSA [14]. They determined the sleep-related outcomes of partial glossectomy as single surgery where possible and as part of multilevel surgery for OSA. They included a total of 522 subjects in their meta-analysis, 498 of them underwent multilevel surgery and the other 24 underwent isolated tongue base surgery. They evaluated the patients based on pre- and postoperative AHI, ESS, lowest O2 saturation (LSAT) and/or snoring visual analog scale (VAS). Table 1 summarizes the study results of Murphey et al. There was a significant improvement in AHI of -27.81, in ESS of -5.49, in LSAT of 7.68 and regarding changes in VAS for snoring as reported by the partner, of -5.60. In 16 out of 18 analyzed studies complictions were mentioned including report of bleeding, wound dehiscence, infection, airway complications, subcutaneous emphysema, prolonged dysphagia, loss or change in taste, delayed surgical intervention, globus and hypoglossal paralysis. Loss or change in taste was reported in 5.81% of the patients, making it the most common complication due to glossectomy, based on the results of this meta analysis.

Table 1 Summary of study results from Murphey et al. [14]

Parameter	N (studies)	N (subjects)	Preoperative	Postoperative
Age	18	522	45.75	
BMI	18	522	29.4	
AHI	17	498	48.1 ± 22.01	19.05 ± 15.46
ESS	10	331	11.41 ± 4.38	5.66 ± 3.29
LSAT	15	414	76.67% ± 10.58%	84.09% ± 7.90%
Snoring VAS	5	197	9.08 ± 1.21	3.14 ± 2.41
Complication rate	16	79		16.4%

TORS Trans oral robotic surgery

A midline glossectomy, starting from foramen cecum down toward the vallecula posteriorly and lingual surface of the epiglottis, is performed through the mouth, removing the lingual tonsils and any excess of tongue musculature. With the use of TORS, midline glossectomy becomes more popular again because of the fact that the da Vinci robot provides a better access to the tongue base, better visualization of the surgical field and because more precision in resection is gained. Tissue removal is thus maximized while the risk to damage vital structures is minimized. In relation to the increased popularity, TORS will be reviewed here apart from glossectomy in general.

A summary of TORS treatment outcomes addressing AHI and ESS is given in table 2. In total, the AHI of 235 patients was measured before and after surgery. Fourty-three of these patients underwent TORS as a standalone procedure, and 192 as part of multilevel surgery for the treatment of OSA. In all the analyzed studies, a significant reduction in AHI was observed. The ESS of 237 patients was evaluated, with a significant overall reduction. These 237 patients can again be divided in patients who underwent TORS alone (25) and those who received TORS in combination with other UA surgery (212).

Table 2 Summary of TORS study outcomes addressing AHI and ESS.

Study	Year	N	Mean Age	BMI	Resection volume (mL)	AHI pre	AHI post	ESS pre	ESS post
Vicini et al. [15]	2012	20	50.2 ± 10.7			36.3 ± 21.1	16.4 ± 15.2	12.6 ± 4.4	7.7 ± 3.3
Friedman et al. [16]	2012	27	43,8 ± 92	32,3 ± 3,3	2,28 ± 0,43	54,6 ± 21,8	18,6 ± 9,1	14,4 ± 4,5	5,4 ± 3,1
Lin et al. [17]	2013	12	46.5 ± 13.3	34.5 ± 7.3	27.6 ± 16.9	43.9 ± 41.1	17.6 ± 16.2	13.7 ± 5.2	6.4 ± 4.5
Toh et al. [18]	2014	20	47.1 ± 11.4	26.5 ± 2.9	9.15 ± 4.1	41.3 ± 22.1	13.5 ± 17.1	13.0 ± 2.8	5.6 ± 4.4
Toh et al. [18]	2014	20						12.4 ± 2.9	6.4 ± 1.4

Glazer et al. [19]	2014	166	54.6 ± 12.3						
Vicini et al. [20]	2014	12	54.2 ± 10.4	27.3 ± 1.2		38.5 ± 14.3	9.9 ± 8.6	12 ± 4.9	4.4 ± 4.1
Vicini et al. [20]	2014	12	49.6 ± 10.8	28.7 ± 3.6		38.4 ± 19.7	19.8 ± 14.1	13.8 ± 4	7.6 ± 4.4
Lin et al. [21]	2015	39	46.5 ± 13.2	32.9 ± 7.0	22.2 ± 11.7	43.9 ± 32.3	21.9 ± 23.5	15.6± 5.4	5.7 ± 4.3
Thaler et al. [22]	2015	75	49.7	32.3 ± 5.61		57.5 ± 23.9	31.4 ± 28.6	12.8 ± 6.5	5.8 ± 4.9
Chiffer et al. [23]	2015	18	46.8 ± 9.0	34 ± 6.5		52.9 ± 24.3	19.8 ± 21.5		

Table 3 summarizes the complications that occurred in response to TORS. The majority of the complications include postoperative hemorrhage, temporary change in taste, tongue numbness and tongue soreness. Most of the complications were general complaints specific for any kind of UA surgery. The majority were minor complications and got resolved after a short period of time.

Table 3 Summery of side effects and complications in the reviewed TORS studies

Study	**Year**	**N**	**Complications**
Vicini et al. [15]	2012	20	minor bleeding (15%) pharyngeal edema (5%) subcutaneous emphysema (10%)
Friedman et al. [16]	2012	27	mild bleeding edema
Lin et al. [17]	2013	12	taste disturbance (few months)
Toh et al. [18]	2014	20	tonsillar bleeding (5%), temporary anterior tongue numbness (100%), temporary tongue soreness (100%), temporary change in taste (55%), slight difficulty in swallowing (5%)
Glazer et al. [19]	2014	166	postoperative hemorrhage (7.2%), mild prolonged dysphagia and globus sensation
Vicini et al. [20]	2014	12	pneumonia
Vicini et al. [20]	2014	12	severe edema, moderate subcutaneous emphysema
Lin et al. [21]	2015	39	oropharyngeal scarring causing dysphagia (7,7%), taste disturbance and tongue numbness, minor taste alterations more than 1 year after surgery (7,7%)
Thaler et al. [22]	2015	75	airway edema (2,7%), postsurgical bleeds (5,3 %)

Radiofrequency (RF)

In this application, radiofrequency energy (RFe) is delivered in a unipolar or bipolar manner from an electrode. A RF generator delivers an alternating current to this electrode in order to generate low heat energy that is sufficient to denaturate tissue proteins. Ionic agitation of the tissue around the electrode is caused, resulting in frictional heating of the tissue. Powell et al. first reported the technique in 1997 [24]. The size of the lesion depends on the current intensity and the time of the energy delivery [24]. The aim of this technique is to reduce tongue volume with minimal collateral damage and stiffen the tongue base to reduce collapse and consequently manage OSA [25]. RF is minimally invasive and can be performed under local or general anaesthesia in patients with social unacceptable snoring or mild OSAS (AHI < 20) when hypertrophy of the tongue is the cause of the disease.

Table 4 and table 5 summarize studies that have been performed on monopolar or bipolar RF in the past. A total of 746 subjects were included in this review. All of them underwent RF surgery as a standalone procedure (table 4) or as part of multilevel surgery (table 5). In the studies of Fischer et al., Woodson et al. and

Steward, RF of the tongue base was combined with RF of the soft palate [26-28]. In total, 564 subjects underwent multilevel surgery and 182 subjects underwent solitary surgery. Overall, a reduction in AHI and ESS can be seen. However, in the study of Welt et al., the daytime sleepiness remained unchanged when the scores before and after surgery were compared. Changes in AHI and ESS in the study of den Herder et al. were not significant either [29]. In addition, van den Broek et al. [30] reported a non-significant AHI decrease.

Table 4 Summary of RF study outcomes addressing AHI and ESS when RF of the tongue base is performed as a standalone procedure.

Study	Year	N	Mean Age	BMI	AHI pre	AHI post	ESS pre	ESS post
Powell et al. [25]	1999	18	44,9 ± 8,68	30,2 ± 5,5	N/A	N/A	10,4 ± 5,6	4,1 ± 3,2
Woodson et al. [31]	2001	56	47,1 ± 9,5	30,6 ± 4,1	40,5 ± 21,5	32,8 ± 22,6	11,1 ± 5,9	7,4 ± 4,6
Stuck et al. [32]	2002	18	49.3 ± 8.46	28,9 ± 2,7	32,1 ± 13,7	24,9 ± 16,8	7,9 ± 5,1	4,9 ± 3,3
Li et al. [33]	2002	16	44,9 ± 8,7	30,2 ± 5,5	N/A	N/A	10,4 ± 5,6	4,5 ± 3,4
Riley et al. [34]	2003	20	49,5 ± 10,7	30,0 ± 5,8	35,1 ± 18,1	15,1 ± 17,4	12,4 ± 2,9	7,3 ± 3
den Herder et al. [29]	2006	22	74,4 ± 9,4	26,7 ± 2,8	9,3 ± 8,4	11,0 ± 8,3 (n=10)	5,7 ± 5,0	3,6 ± 3,3
Welt et al. [35]	2007	20	41,9 ± 8,1	26,2 ± 3,3	N/A	N/A	6,0 ± 3,7	6,2 ± 3,1
Fibbi et al. [8]	2009	12	50,2 ± 9,1	28,3 ± 1,0	15,2 ± 2,8	9,8 ± 3,2	9,9 ± 2,0	8,2 ± 3,2

Table 5 Summary of RF study outcomes addressing AHI and ESS when RF of the tongue base is performed as part of multilevel surgery.

Study	Year	N	Mean Age	BMI	AHI pre	AHI post	ESS pre	ESS post
Nelson et al. [36]	2001	9	51,5	27,9	29,5 ± 14,8	18,8 ± 14,6	12,5 ± 3	6,5 ± 2,5
Fischer et al. [26]	2003	15	56,9 ± 11,1	27,3 ± 2,6	32,6 ± 17,4	22,0 ± 15,0	11,1 ± 4,7	8,2 ± 4,7
Woodson et al. [27]	2003	26	49,4 ± 9,2	27,7 ± 3,6	21,3 ± 11,1	N/A	11,9 ± 4,6	9,8 ± 3,9
Steward [28]	2004	22	46,9 ± 9,9	30,3 ± 5,0	31,0 ± 17,7	26,6 ± 16,8	11,4 ± 4,1	N/A
Jacobowitz [37]	2006	27	47,6 ± 12,1	29,9 ± 4,1	49,9 ± 25,5	14,9 ± 17,6	12,1 ± 4,9	6,7 ± 3,7
Nelson et al. [38]	2007	98	42	28	35,4 ± 23,9	24,3 ± 21,5	11,2 ± 4,9	5,9 ± 4,5
Eun et al. [39]	2008	66	44,7 ± 10,6	27,6 ± 3,4	22,9 ± 14,7	13,9 ± 18,7	11,4 ± 5,0	7,5 ± 4,5
van den Broek et al. [30]	2008	37	49	26,4 ± 3,2	17,8 ± 10,3	11,2 ± 10,8	N/A	N/A
Ceylan et al. [40]	2009	26	46,3 ± 3,9	28,6 ± 2,7	29,6 ± 7,8	16,1 ± 3,9	10,8 ± 3,2	8,2 ± 2,7
Neruntarat et al. [41]	2009	72	35,8 ± 10,9	28,8 ± 2,4	35,6 ± 9,2	16,8 ± 3,2	14,2 ± 3,4	8,2 ± 2,5
Fernandez-Julian et al. [9]	2009	29	47,2 ± 6,0	29,2 ± 1,6	32,5 ± 8,0	15,4 ± 7,6	13,9 ± 1,3	9,7 ± 2,3
Lin et al. [42]	2010	43	39	27,9 ± 3,9	51,5 ± 25,4	23,4 ± 24,7	12,8 ± 5,1	10,0 ± 4,3
Babademez et al. [43]	2011	15	48,2 ± 7,1	N/A	22,7 ± 12,3	10,4 ± 10,6	8,4 ± 7,2	1,8 ± 0,8
Plzak et al. [44]	2013	79	50,5 ± 9,1	28,1 ± 3,1	28,7 ± 17,1	14,1 ± 18,2	10,6 ± 3,8	7,3 ± 3,2

Table 6 summerizes the mean total amount of RFe deliverd per patient, the mean number of treatment sessions in the tongue, the mean number of treatments in each session, the duration and temperature that was used in the different studies.

Table 6 Summery of delivered RFe.

Study	Year	N (subjects)	Total mean energy (J)	N (treatment sessions)	N (treatments/ session)	Duration (sec)	Temperature (°C)
Powell et al. [26]	1999	18	8490 ± 2687	5,5	1,82	540	80
Nelson et al. [36]	2001	9	12000	3	2 to 6		85
Woodson et al. [31]	2001	56	13394 ± 5459	5,4 ± 1,8	3,1 ± 0,9		

Li et al. [33]	2002	16	8490 ± 2687	5,5	1,82	540	80
Riley et al. [34]	2003	20	5636 ± 1042	4,6 ± 0,6			
den Herder et al. [29]	2006	22	504 to 1512	1,5			
Nelson et al. [38]	2007	98	10500	1	14		85
Eun et al. [39]	2008	66	540				
van den Broek et al. [30]	2008	37	252				
Fibbi et al. [8]	2009	12	2400		3	20	
Neruntarat et al. [41]	2009	72		4,8 ± 0,8			
Fernandez-Julian et al. [9]	2009	29	9000	3	4		85
Lin et al. [42]	2010	43	4500 to 7500				

The complications and side effects as a consequence of RF are summarized in table 7. Ulcerations were most seen, followed by edema. Complications were resolved over time and thus RF can be seen as a safe, well-tolerated treatment for OSA.

Table 7 Summery of side effects and complications in the reviewed RF studies

Study	Year	N	Complications
Powell et al. [25]	1999	18	ulceration (1) recurrent dysphagia (1) abscess (1)
Woodson et al. [31]	2001	56	ulceration (7) edema (3) thrush (1) abscess (1) temporary palsy hypoglossal nerve
Stuck et al. [32]	2002	18	ulceration (2) recurrent dysphagia + edema (4) abscess (1)
Riley et al. [34]	2003	20	temporary neuralgia (1)
Woodson et al. [27]	2003	26	hematoma (3) ulceration (1)
Steward [28]	2004	22	ulceration (3) hematoma (2)
Jacobowitz [37]	2006	27	tonsillar fossa hemorrhages (2) temporary oronasal reflux (3)
Nelson et al. [38]	2007	98	superficial base of tongue ulcers (5) long-term taste disturbances (3)
Fibbi et al. [8]	2009	12	edema mucosal erosion pharyngodynia
Eun et al. [39]	2008	66	ulceration of the tongue base taste change
van den Broek et al. [30]	2008	37	transient tongue deviation and loss of sensibility edema

Neruntarat et al. [41]	2009	72	lingual ulcer (6) dysphagia (6) swelling of the floor of the mouth (5) aspiration (5)
Fernandez-Julian et al. [9]	2009	29	temporary mild tongue base mucosal ulceration (1)
Lin et al. [42]	2010	52	bleeding from oropharyngeal wound temporary velopharyngeal insufficiency (VPI) temporary ear fullness or pressure throat discomfort
Plzak et al. [44]	2013	79	ulceration (4) taste change (1)

Tongue suspension

DeRowe et al. first described the tongue suspension suture technique [45]. A bone screw is incisionless placed into the lingual cortex of the mandibular symphasis. Then, an attached suture of proline is looped into the posterior tongue base and tied anteriorly. The suture supports the anterior hypopharyngeal airway and tongue base, which, in theory, prevents obstruction. The aim is to stabilize and support the tongue base level by adding rigidity of the scar tissue. The technique is reversible and minimal invasive, which are major advantages. A disadvantage on the other hand, is the fact that the advancement of the tongue is not titratable, thus, no more modifications to the advancement of the tongue can be made once the knot forming the suspension suture is tied.

In table 8, BMI, preoperative and postoperative AHI and ESS are presented. In total, 113 patients underwent tongue base suspension as a standalone surgery in the treatment of OSA. The majority of the patients (N=332) underwent tongue base suspension in combination with UPPP. Overall there were 445 patients included and a significant decrease in AHI and ESS after surgery can be observed.

Table 8 Summary of AHI values before and after tongue suspension surgery.

Study	Year	N	Age	BMI	AHI pre	AHI post	ESS pre	ESS post
DeRowe et al. [45]	2000	14	54,7 ± 10,5	N/A	35 ± 16,5 (RDI)	17 ± 8 (RDI)	N/A	N/A
Woodson et al. [46]	2000	9	45,6 ± 8,3	28,2 ± 4,0	33,2 ± 13,5 (RDI)	17,9 ± 8,1 (RDI)	13,2 ± 3,7	8,5 ± 3,0
Woodson et al. [47]	2001	14	47,1 ± 8,0	28,0 ± 3,9	35,4 ± 13,7 (RDI)	24,5 ± 14,5 (RDI)	13,8 ± 3,9	8,8 ± 2,8
Miller et al. [48]	2002	15	48,8 ± 9,5	31,3 ± 4,9	38,7 ± 12,3 (RDI)	21,0 ± 7,4 (RDI)	N/A	N/A
Terris et al. [49]	2002	12	44,9 ± 14,2	31,5 ± 7,2	42,8 ± 24,8	N/A	11,0 ± 5,4	5,4 ± 3,8
Sorrenti et al. [50]	2003	15	50,5	28,3	44,5 (RDI)	24,2 (RDI)	11,2	6,6
Thomas et al. [51]	2003	9	50,8 ± 16,1	30,9 ± 6,2	46,0 ± 22,0	N/A	12,1 ± 7,2	4,1 ± 3,4
Kühnel et al. [52]	2005	25	50 (median)	31	40,6 ± 33,6 (RDI)	27,2 ± 27,1	12,4 ± 4,4	8,8 ± 3,7
Kühnel et al. [52]	2005	23	50 (median)	31	44,0 ± 33,3	30,6 ± 28,1	12,8 ± 4,8	9,3 ± 4,2
Omur et al. [53]	2005	22	44,5 ± 8,0	30,3 ± 3,8	47,5 ± 15,7 (RDI)	17,3 ± 14,2 (RDI)	13,9 ± 2,2	5,4 ± 4,3
Vicente et al. [54]	2006	54	47,3 ± 4,5	29,6 ± 4,8	52,8 ± 14,9	14,1 ± 23,5	12,2 ± 3,3	8,2 ± 6,1
Fibbi et al. [8]	2009	12	47,9 ± 8,3	28,5 ± 1,4	14,8 ± 3,1	4,7 ± 3,2	5,9 ± 3,6	3,2 ± 1,6
Fibbi et al. [8]	2009	12	47,9 ± 8,3	28,5 ± 1,4	14,8 ± 3,1	8,7 ± 5,0	5,9 ± 3,6	4,1 ± 2,5
Fernandez-Julian et al. [9]	2009	28	45,5 ± 4,9	29,0 ± 1,6	33,1 ± 7,9	15,1 ± 6,1	13,5 ± 1,4	9,1 ± 2,6
Sezen et al. [55]	2011	8	44,4 ± 6,3	29,8 ± 2,0	18,2 ± 2,9	8,0 ± 6,0	12,5 ± 2,4	5,0 ± 3,1
Sezen et al. [55]	2011	12	48,3 ± 8,8	30,9 ± 2,8	28,8 ± 10,7	15,3 ± 11,1	14,8 ± 2,5	7,6 ± 3,2
Li et al. [56]	2013	45	40,3 ± 12,8	27,7 ± 3,6	39,4 ± 17,8	8,9 ± 5,9	12,9 ± 4,9	3,4 ± 2,9

Huang et al. [57]	2014	30	39,2	27,0 ± 3,1	46,7 ± 19,8	23,7 ± 20,0	N/A	N/A
Turhan et al. [58]	2015	31	48 (median)	31,0 ± 2,4	44,7 ± 17,1	20,0 ± 19,5	N/A	N/A
Turhan et al. [59]	2015	90	48 (median)	30.7 (median)	51,8 ± 18,8	20,5 ± 17,7	N/A	N/A

Data on complications are provided in table 9. In a few cases, the suture had to be removed. All the other complications and side effects resolved after a certain amount of time. Additional to these studies, Akcam et al. compared early postoperative pain among surgical techniques for obstructive sleep apnea [60]. They concluded that tongue base suspension suture is the most painful surgery in the context of surgery as treatment for OSA. In order to alleviate the pain, rescue opioid analgesics are usually needed around the first hour. Routine administration of opioid is consequently advisable at this time.

Table 9 Summary of side effects and complications in the reviewed tongue base suture surgery studies

Study	Year	N	Complications
DeRowe et al. [45]	2000	14	pain odynophagia speech difficulties mouth floor cyst
Woodson et al. [46]	2000	9	dislocated tooth (1) delayed floor of mouth sialadenitis (4) delayed gastro-intestinal bleeding (1) dehydration (1)
Woodson et al. [47]	2001	14	delayed floor of mouth sialadenitis (4) dysphagia (1) delayed gastro-intestinal bleeding (1)
Miller et al. [48]	2002	15	acute submandibular sialadenitis (2) floor of mouth hematoma (1) extrusion of the suture (1) persistent globus sensation in the base of tongue (suture removed 6 weeks postoperatively)
Terris et al. [49]	2002	12	transient velopharyngeal insufficiency (4) limited anterior excursion of the tongue (2)
Kühnel et al. [52]	2005	25	broken suture (1) disturbed sensation at the tip of the tongue, associated with temporary unilateral lungual atrophy unilateral hypesthesia of the tongue tip extrusion of the suture in the anterior part of the floor of the mouth (3) infection of the floor of the mouth (explantation) dimple at tongue base was no longer palpable in the same way
Omur et al. [53]	2005	22	bleeding and swelling into the floor of the mouth (1) broken suture (1) delayed floor of the mouth infection (2) dysphagia, odynophagia, dysarthria, pain limited extention of the tongue
Vicente et al. [54]	2006	54	septoplasty (21)
Fibbi et al. [8]	2009	12	hematoma edema of the floor of the mouth

			odynophagia mechanical dyslalia
Fernandez-Julian et al. [9]	2009	28	swelling in the floor of the mouth (4) acute submandibular sialadenitis (2)
Li et al. [56]	2013	45	transient nasopharyngeal reflux (2), reduced flexibility, a sense of a foreign body when swallowing, and slurred speech (12)
Huang et al. [57]	2014	30	mouth floor oedema and hematoma,
Turhan et al. [58]	2015	31	Swelling in the base of the mouth (2) granulated tissues in submental region (2) suture came apart (1) complaints of foreign matter and feeling of an obstruction within the troat (suture removed) (1) minimal to mild throat pain, difficulty in swallowing and speaking in the first 3 days (all)

Adjustable tongue advancement

In this approach, an implant consisting of a tissue anchor and a titration spool is incorporated in the tongue base and attached to the mandible. The implant provides an advancement of the tongue base, resulting in increased airway space and reduced tendency of the tongue to collapse during sleep. A titration procedure is performed by adjusting the tension on the tissue anchor which is responsible for the connection of the spool on the bone anchor. In this way, the tongue can be advanced anteriorly or relaxation of the tongue in order to fall more posteriorly can be achieved. It is a minimally invasive technique that is reversible if required. The aim is to stabilize the tongue, resulting is the maintaining of an open airway, for the reduction of the incidence of tongue based OSA.

In table 10, the results on the use of the Advance System (Aspire Medical, Sunnyvale, California) studied by Hamans et al. and Woodson et al. and the Advance System II (Aspire Medical, Inc., Sunnyvale, CA) studied by Pavelec et al. are presented [61-63]. Both studies on the first Advance System report a significant decrease in AHI and improvement of VAS scores 6 months after surgery. A non-statistically significant reduction in ESS from 11.4 to 7.7 was observed by Hamans et al. (N=10), while in a larger group in the study of Woodson et al. (N=42) a significant reduction from 11.5 ± 3.9 to 7.8 ± 4.7 was found. There were some complications and side effects observed in the study of Hamans et al. but they were mainly due to the technical learning curve. Woodson et al. reported some significant complications such as tongue base tissue anchor barb fracture (31%), wound infection or cellulitis (7%), edema/seroma (5%), failure of the bone anchor locking mechanism which prevented titration (2%), and one bone anchor was repositioned under local anesthesia as a consequence of surgical error and placement off midline.

The study of Pavelec et al. was prospectively designed to assess the feasibility, safety, and preliminary efficacy of the new Advance System II. In this new system, barb breakage of the prior generation of the Advance System was successfully addressed. However, a new malfunction of the bone anchor was found. The tether line in four patients slipped so that the titration spool did not maintain the titrated position. As a consequence, posterior movement of the tongue was allowed. Before the spool release, improvement of the disease was observed in these patients.

Table 10 Summary of AHI, ESS VAS scores before and after tongue suspension surgery and complications and side effects.

Study	Hamans et al. [61]	Woodson et al. [62]	Pavelec et al. [63]
Year	2008	2010	2011
N	10	42	19
Mean Age	44 ± 10,0	50,01 ± 9,1	49,1 ± 7,6
BMI	26,6 ± 2,7	27,8 ± 2,1	26,8 ± 3,2
AHI pre	22,8	35,5 ± 20,4	34,3 ± 19,9
AHI post	11,8	27,4 ± 18,8	24,3
ESS pre	11,4	11,5 ± 3,9	11,3
ESS post	7,7	7,8 ± 4,7	7,4
Snore VAS pre	7,5	7,3 ± 2,1	

Snore VAS post	3,9	1,4	
Mean tongue advancement	4,7 ± 2,9	1,3 ± 0,3	
Complications	submental granuloma at incision spot	wound infection or cellulitis edema/seroma	bilateral hearing loss of 50 dB on both ears

Discussion

Partial glossectomy is mostly studied as part of multilevel surgery. A detailed discussion in the context of this surgery, can be found in the review article of Murphey et al. [14]. In short, it was shown that glossectomy as part of multilevel surgery significantly improves sleep outcomes in selected adult OSA patients. An overall reduction of 61% in AHI, 51% in ESS and 65% in VAS for snoring and an increase in LSAT was observed. For the effect of glossectomy as a standalone surgery in the treatment of OSA, there was not enough evidence.

In the current review, the use of TORS as a standalone procedure and as part of multilevel surgery is researched. As part of glossectomy, TORS is mainly studied in the context of the latter, and more specific in combination with UPPP. The combination of TORS with UPPP as multilevel surgical treatment appears to be effective. The AHI and ESS outcomes improved significantly after surgery. The best results were seen in the study of Vicini et al. [20], in the group of patients who underwent a complete reshaping of the upper airway including nose surgery if required, in combination with TORS according to the Vicini (C.V.)-Montevecchi (F.M.) technique and a nonrobotic expansion sphincter pharyngoplasty according to Pang-Woodson as palate surgery, with minimal modifications. In this group of patients, a reduction in AHI of 74% and in ESS of 63% was observed. In the study of Thaler et al., the best outcomes were obtained in those patients who had had no prior surgery and underwent TORS in addition to UPPP in the same stage [22]. In the current review, only 43 subjects who underwent TORS as a sole surgery for OSA could be identified. Although this is a small group, the results are promising. An overall reduction in AHI and ESS could be observed in these patients. When all the reviewed studies are included, a overall mean reduction of 59% in AHI and 54% in ESS can be observed with TORS for OSA.

RF can be performed in order to reduce the tongue tissue volume and in order to stiffen the tongue base. By using RF, multiple levels of the airway can be treated and it can be repeated over time with minimal morbidity. In this review, the overall results show a decrease in AHI and ESS in patients who underwent RF as a standalone intervention or as part of multilevel surgery. The best AHI (70% reduction) and ESS (79% reduction) outcomes were seen by Jacobowitz and Babademez et al., respectively [37, 43]. The overall mean reduction in AHI was 42% and 37% in ESS. Most of the studies were carried out on a short-term basis. Long-term follow-up is needed as a proof of long-term efficacy of the treatment. Despite the great success rates in the short-term follow-up, the results of the study of den Herder et al., showed that long-term effects were not stable [29]. Woodson et al. compared the use of CPAP with multilevel RF treatment. They found that both treatment options were equally effective in improving levels of daytime sleepiness [27]. The patients in most of the studies were overweight but not obese. It can be concluded that, as in other surgical procedures for OSA, patient selection is important to increase the chance of success [64]. RF therapy can be seen as a safe, well-tolerated, minimal invasive procedure that is clinically effective. The technique is easy to perform and in the context of multilevel surgery, it does not lead to serious adverse events. A limitation in the research is the small size of treated patient groups. Based on the results of this review, RF can be considered as first choice in treating mild OSA as a stand-alone therapy. However, in the case of moderate or severe sleep apnea, RF is proven to be not sufficient as a solitary treatment and could therefore be considered as an additional therapy to other treatment options to increase success rates.

Tongue base suspension is considered as a minimally invasive technique that is easy to use. The results in this review illustrate long-term efficacy of tongue suspension. There is an overall reduction in AHI and ESS of 52% and 45% respectively. All complications that occurred got resolved over time. Li et al. obtained best results with an AHI reduction of 77,4% and a reduction in ESS of 73,6% [56]. The technique proved to be efficient as a standalone procedure and as part of multilevel surgery [65]. Besides the pain that is caused by this kind of surgery, another major disadvantage is the fact that it is not adjustable meaning that no more modifications to the advancement of the tongue can be made once the knot forming the suspension suture is tied. In order to overcome this problem, the adjustable tongue advancement system was developed. A modified system (Encore system, Siesta Medical) is now on the market. This system is titratable and minimal invasive implantable [65].

Only three studies are published in the context of the adjustable tongue advancement. All studies show a decrease in AHI and an improvement in VAS for snoring. A reduction in ESS could be seen in both studies that assessed the original Advance System but was only proven to be significant in the study of Woodson et al. [62]. The overall mean AHI reduction amounts 35% and the overall mean ESS reduction amounts 32%. Although both studies showed promising results, Woodson et al. reported a high and unacceptable device tissue anchor failure rate, resulting in failure as a clinical device. However, the results showed success which is supportive for the concept of adjustable tongue advancement and modification of the system should result in a promising treatment option in OSA in the future.

The anchor was improved in the study of Pavelec et al. [63]. The Advance System II, as an improvement of the tongue anchor, again showed an AHI reduction rate of 30% and a ESS reduction rate of 34%. The feasibility and safety rates are satisfactory but there is still room for improvement. However, in this study there were cases of malfunction of the bone anchor, causing the necessity to further improve the device. If the slippage issue is solved, the adjustable tongue advancement system may potentially play an important role in the treatment of OSA because of the major advantages of the system. It is a minimal invasive procedure that is reversible and adjustable. The adjustability ensures that discomfort to the patient can be avoided.

When the five techniques that are reviewed here are mutually compared, the highest AHI reduction rates are obtained in glossectomy, followed by TORS and tongue suspension. For ESS, the best outcomes were acquired in TORS, followed by glossectomy and tongue suspension. All these types of treatment can be used as a standalone procedure but are recommended as part of multilevel surgery in order to obtain the best and more significant result. Patient selection in every type of surgery is important to secure success rates [64].

Conclusions

In summary, the results of this review suggest that glossectomy is associated with the highest success rate among the studied types of soft-tissue surgery of the tongue. TORS, as part of glossectomy is gaining popularity and is proven to be safe and efficient. Multilevel surgery is preferable in most patients in order to obtain best results. The long-term effectiveness of the reported treatment options addressing the soft tissue of the tongue for OSA still needs to be proved.

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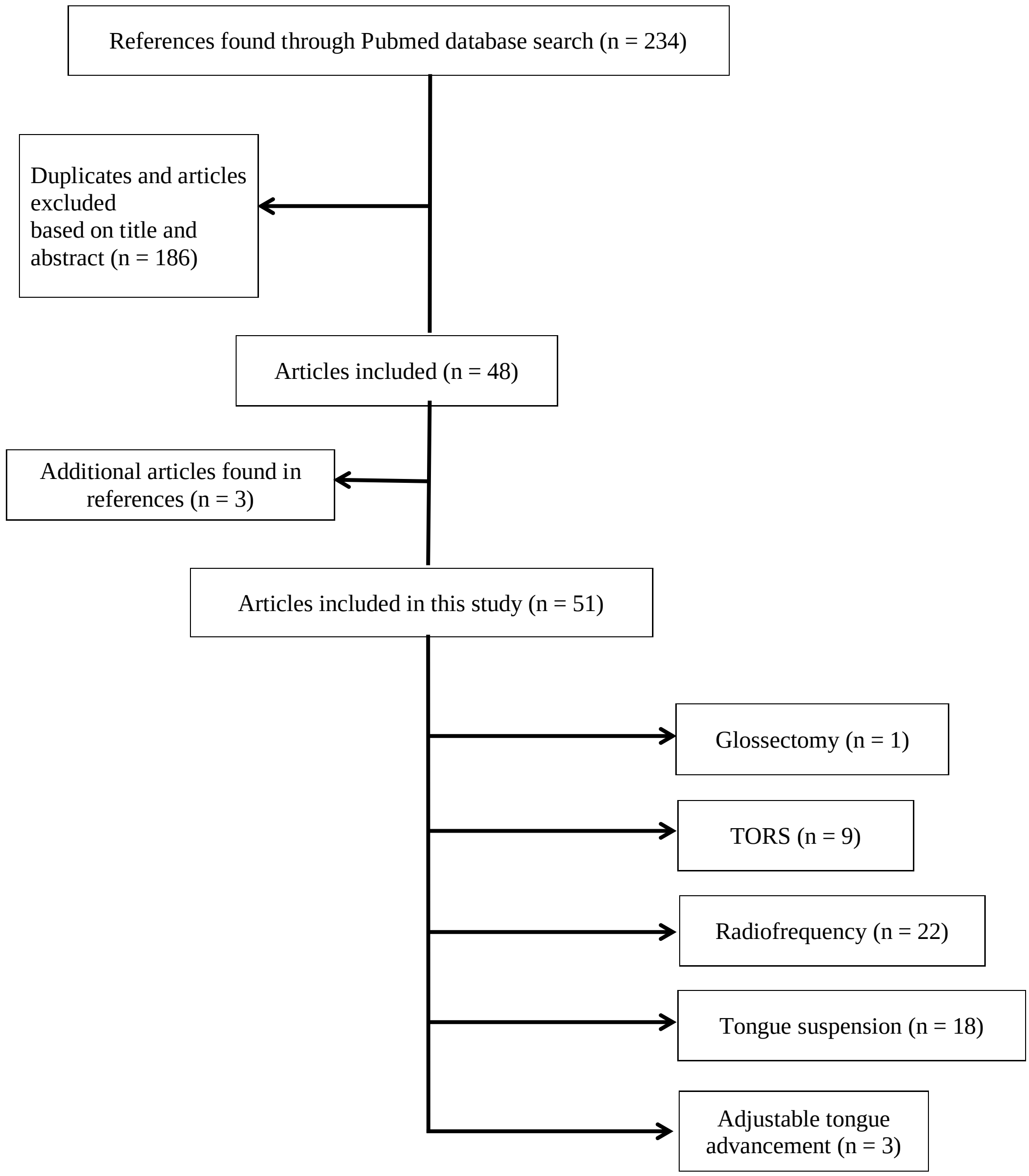

Figure 1 Search strategy.