8 Genioglossus Advancement

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8.1 Introduction

Since the initial description of a mandibular osteotomy procedure to increase the hypopharyngeal space in 1984, genioglossus advancement surgery (GGA) has been used on its own or more commonly in combination with uvulopalatopharyngoplasty (UPPP), hyoid myotomy, and suspension in patients with obstructive sleep apnea (OSA) [1]. In some severe cases of OSA, this procedure is also used in combination with maxillomandibular advancement (MMA). The genioglossus muscle acts as a major pharyngeal dilator and is believed to play a significant role in closure of the airway during sleep-induced hypotonia of oropharyngeal muscles [2]. This muscle plays an important role in retaining an open-air passage in the oropharynx and during sleep; genioglossus activation is influenced by numerous variables, including sleep-wake status, intrapharyngeal negative pressure, blood gases, arousal, respiratory control, and fatigue [3–5].

Fujita used a classification system to describe the level of collapse seen in patients with OSA [6]. Type I describes abnormalities of the upper oropharyngeal airway, including the palate, uvula, and tonsils. Type II consist of upper oropharyngeal and hypopharyngeal airway pathology, and type III involves only the hypopharyngeal airway (i.e., lingual tonsils, tongue base, supraglottis, and hypopharynx). The relevance of targeting the appropriate level of airway collapse was further illustrated by Sher and colleagues, who reported only 5% success in patients with retrolingual (types II and III) collapse who undergo a uvulopalatopharyngoplasty (UPPP) alone [7].

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The rationale of GGA surgery is to stabilize the hypopharyngeal airway by the forward movement of the genial tubercle and hence the genioglossus muscle, which will advance the tongue and induce tension at the base of the tongue. This will, therefore, reduce the likelihood of collapse of the tongue backward into the posterior airway during sleep making this a more appropriate procedure for those patients with type II and type III obstruction. In this chapter we will review the relevant anatomy, history of the procedure, its role in current day practice, and different techniques.

8.2 Anatomy

The genioglossus muscle has been extensively scrutinized in the context of obstructive sleep apnea. This is because of its involvement in hypopharyngeal airway collapse and resultant obstructions noted especially during sleep stages with decreased neuromuscular tone (i.e., REM atonia). The genioglossus muscle is a paired, fan-shaped extrinsic tongue muscle. It arises from the superior genial tubercles of the mandible, and occasionally some fibers also take origin from the adjacent surface of the mandible lateral to the superior genial tubercles. The muscle inserts into the body of the hyoid bone, the tip of the tongue and throughout the dorsum of the tongue. The superior fibers retract the tip of the tongue, whereas the middle fibers depress the dorsum of the tongue [8]. The inferior fibers advance the hyoid anterior-superiorly. The muscle is innervated by cranial nerve 12 and receives its major vascular supply from the lingual arteries bilaterally.

The geniohyoid muscle is found just inferior to the genioglossus muscle taking its origin from the inferior genial tubercles. It then runs posteriorly and inferiorly, to be inserted into the anterior surface of the body of the hyoid bone. This muscle also dilates the upper airway through its action of moving the hyoid bone upward and forward.

The genial tubercles are bony spines on the lingual surface of the mandible near the midline, and there are two pairs. The superior genial spines are almost always paired bilaterally although on occasions they are found fused together. In contrast, the right and left inferior genial spines were usually indistinguishable. The anatomy of the genial tubercles, especially its relation to the apices of the lower central incisors is of utmost importance in the context of GGA surgery. Although radiographs may give an indication of the relation of the mandibular incisors to the genial tubercles, there is an approximate magnification of 8% in periapical radiographs and 30% in panoramic radiographs. Therefore, preoperative assessment with three-dimensional imaging is preferred.

A cadaver study by Silverstein and Costello found the average distance from the apex of the incisors to the genial tubercle was 11.8 mm with a range of 9–15 mm [8]. However, another anatomical assessment using measurements from CT scans and dry cadaveric skulls found the average distance between the apices of the roots of the mandibular central incisors to the superior genial tubercles was 6.45 mm [9]. The same study also observed that 35% of the genial tubercles were situated within 5 mm from the apices of the mandibular incisor teeth which may increase the risk for devitalization of teeth as determined by Bell's angiographic studies [10]. In

1988, morphological measurements on ten human cadaver half-heads found a range of 2.5–13 mm (mean 6.83 mm) between the incisor apex and the superior genioglossus muscle attachment [11]. Our clinical experience is consistent with a wide variation in genial tubercle positions and tooth root lengths that require identification with three-dimensional (3D) imaging.

8.3 History and Evolution of the GGA Technique

The first procedure described by Riley et al. in 1984 employed an intraoral approach, and the osteotomy design was similar to an advancement genioplasty [1]. The hyoid bone was also fixed to the inferior border of the mandible after myotomy of the infrahyoid muscles. This is referred to as the genioglossus advancement/hyoid myotomy. This procedure was further modified by Riley and colleagues in 1986 to retain the continuity of the lower border of the mandible by limiting the osteotomy to a rectangular window of the bone in the anterior mandible containing the genial tubercles and genioglossus muscle complex [12]. The bone-muscle flap is advanced and rotated 30–45° to create bone overlap for a fixation screw (Fig. 8.1). This was referred to as the anterior mandibular osteotomy. This modification reduced the risk of fracture of the mandible which was reported in prior techniques. However, rotation of the flap may create excessive tension possibly resulting in detachment of the muscle complex. One of the other limitations of this procedure is the risk of injury or devitalization of the anterior mandibular dentition.

Variations of this procedure include different types of osteotomies and alteration in transposition of the bone segment [12–18]. In 1993 Riley et al. put forward the Stanford protocol where each patient was classified according to the site of obstruction (type I, oropharynx; type II, oropharynx/hypopharynx; and type III, hypopharynx) [13]. In phase I surgery, patients with type I obstruction (soft palate) receive UPPP, and patients with type III obstruction (base of tongue) receive genioglossus advancement/hyoid myotomy (GAHM). Patients with type II (palate and base of tongue) receive UPPP and GAHM together. Patients who failed phase I surgical

Fig. 8.1 Cadaver dissection demonstrating a rectangular osteotomy with genioglossus muscle placed under tension via advancement and rotation (Reprinted with permission from Li KK, Riley RW, Powell NB et al. Obstructive sleep apnea surgery: Genioglossus advancement revisited. *J Oral Maxillofac Surg*. 2001; 59:1181–1184)

procedures were then recruited into phase II where they were offered maxillomandibular advancement (MMA) surgery.

In 1998, David Dattilo designed the mandibular trapezoid osteotomy through an extraoral approach to allow the maximum advancement of the musculature in a natural and functional position while minimizing esthetic profile changes to the lower facial third [14].

In 2000, Lee and Woodson introduced the Genial Bone Advancement Trephine (GBAT) system (Stryker Leibinger Corporation) which boasted greater ease of isolation and advancement of the genioglossus muscle [15]. This system incorporated a guide plate and trephine (12–14 mm) to create a circular osteotomy for capture of the genial tubercles. A prebent fixation plate matches the osteotomized segment, allowing for advancement and fixation with minimal manipulation. The proponents of this technique claim reduced operating time, fewer postoperative complications, and reliable capture of the genial tubercles. However, localization of the tubercles was based on panoramic radiographs and palpation only.

In 2001, Hendler et al. proposed the mortised genioplasty technique with the goal of achieving greater expansion of the hypopharyngeal airway through advancement of the genioglossus, geniohyoid, mylohyoid, and anterior belly of digastric muscles simultaneously (Fig. 8.2). This technique uses a rectangular box superiorly to capture the genial tubercles, with the inferior aspect of the box extended laterally as in a standard genioplasty technique. Fixation is applied laterally on both sides to lessen the risk of mandibular fracture [16]. This technique is ideally suited for patients who benefit esthetically from a genioplasty advancement. Despite the hypothesized airway expansion described by the authors, changes in airway dimensions have not been studied. Moreover, compared to a window technique which is limited to capturing the genial tubercle attachments, the mortised genioplasty may be more susceptible to relapse given a stronger posterior muscle pull and bony

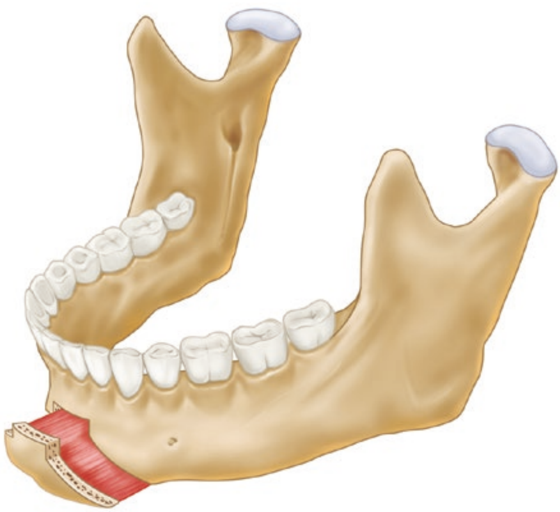

Fig. 8.2 Mortised genioglossus advancement design to capture the genioglossus, geniohyoid, and anterior digastric muscles (Reprinted with permission from Silverstein K, Costello BJ, Giannakkpoulos H, et al. Genioglossus muscle attachments: An anatomic analysis and the implications for genioglossus advancement. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 90: 687, 2000)

union limited to the superior border of the osteotomy. Interestingly, relapse of anterior segmental osteotomies for GGA have not been studied.

In 2009, Demian and colleagues described a technique that allows complete capture and advancement of the genial tubercles along with the entire genioglossus complex without noticeable changes in the soft tissue esthetics [17]. This is accomplished by carrying the horizontal osteotomy to just medial of the canine roots and extending the vertical cuts to the inferior border. The whole complex is advanced and the buccal cortex and cancellous bone removed, leaving the lingual cortex with the attached musculature. This is then fixed with a prebent plate across the inferior border to minimize alteration in chin contour. The authors claim this technique combines the advantages of inferior mandibular osteotomy procedure and the rectangular box osteotomy.

Another modification of the conventional rectangular GGA osteotomy describes the creation of a bony groove in the basal bone inferior to the osteotomy in order to accommodate the muscle complex while maximizing the advancement with fixation of the lingual plate using positional screws anterior and inferior (to the window osteotomy) over the inferior border [18]. This technique avoids the 90° rotation which places torquing stress on the muscle attachment at the tubercle and increases the risk of detachment or vascular compromise. For patients with mild retrogenia, the authors also claim a more pleasing aesthetic outcome as compared to the latter technique which may blunt the labiomental fold [18].

8.4 Preoperative Evaluation

Patients considered for surgical treatment of OSA undergo a complete medical history and physical examination, fill out validated instruments to assess hypersomnolence (Epworth Sleepiness Scale) and sleep quality (Pittsburgh sleep quality index), undergo a polysomnogram (PSG) to establish the diagnosis and severity of sleep-disordered breathing, and have an assessment of the upper airway via fiberoptic nasoendoscopy and cone beam computed tomography (CBCT).

Exam findings which increase the risk of OSA include obesity, adenotonsillary hypertrophy, retrognathia, micrognathia, macroglossia, a low hyoid position, elongated soft palate, deviation of the nasal septum, turbinate hypertrophy, a thick short neck, or mass lesions in the nasopharynx or hypopharynx. Conditions like trisomy 21, myxedema, goiter, acromegaly, and lymphoma may be associated with OSA, owing to their effects on the upper airway anatomy.

PSG: A full-night polysomnography is carried out to assess the following parameters—total sleep time, sleep stages NREM and REM (via electrooculogram), as well as percent of sleep in each, electroencephalography, chest and abdominal movements, snoring, nasal airflow, lowest oxygen saturation, lower limb movement (via electromyography), and electrocardiographic activity. The severity as an index is summarized as apnea-hypopnea index (AHI).

Fiberoptic nasoendoscopy is performed to determine the extent of airway obstruction while the patient is supine at rest and during forced inspiration or

Mueller maneuver. Posterior septal deviation, enlargement of the inferior turbinate, and nasopharyngeal lesions are some of the abnormalities that may be better appreciated by endoscopic evaluation. The Mueller maneuver is performed while the patient is upright with a closed mouth and pinched nose with maximum inspiration. The increased intraluminal negative pressure with this maneuver attempts to duplicate the sleep-related pressure changes to more accurately assess the presence of dynamic upper airway collapse. Because the patient is awake when this is performed, and upper airway muscles maintain their tone, false-positive and false-negative results are possible [19]. A five-point scale provides a more objective measure to rate the sites of collapse during the Mueller maneuver to increase its reliability [20].

CBCT: Visualization of the upper airway with CBCT scans provides important 3-dimensional information about surrounding structures and their contribution to, as well as the specific location of, airway obstruction [21]. Airway space measurements, including volume and cross-sectional area, have been shown to be quite accurate by use of CBCT scans. Multivariate analysis shows both retroglossal space and retropalatal space narrowing to be predictive of an elevated respiratory disturbance Index (RDI) [22]. The relationship between the airway area and the likelihood of OSA has been previously demonstrated [23]. Finally a CBCT is used for virtual surgical planning including intraoperative osteotomy design and positioning or cutting guides which allows precise capture of the genial tubercle, while avoiding injury to key surrounding structures [24].

Hueman et al. in their effort to determine the accuracy of CBCT to predict the location of the genial tubercle looked into the width of the genial tubercle, genial tubercle height, distance from inferior border of mandible to genial tubercle, mandibular height, and mandibular thickness. No significant difference was found in mean distances between cadaver dissections vs the 3D cone beam CT [25].

8.5 Virtual Surgical Planning

There have been various attempts to study the anatomy of the genial tubercles to design the perfect osteotomy that would incorporate maximum capture of the tubercles along with the muscle complex while minimizing the risks of instrumenting in proximity to the apices of adjacent mandibular teeth. Given the anatomical variability between individuals, the ideal osteotomy design should be customized to suit the individual situation.

Over the past few years, the use of virtual surgical planning (VSP) and computer-aided design and manufacturing (CAD/CAM) has created a paradigm shift in the diagnosis and planning of orthognathic and craniofacial procedures. The authors now regularly employ virtual surgical planning in all GGA procedures to enable 3-dimensional visualization in order to confirm the feasibility of the procedure. For this purpose, DICOM files containing CBCT data and stone models or STL files of an intraoral scan are obtained. Patient with an excessively thin symphysis <8 mm (A-P dimension) or those with <5 mm of vertical clearance between the superior

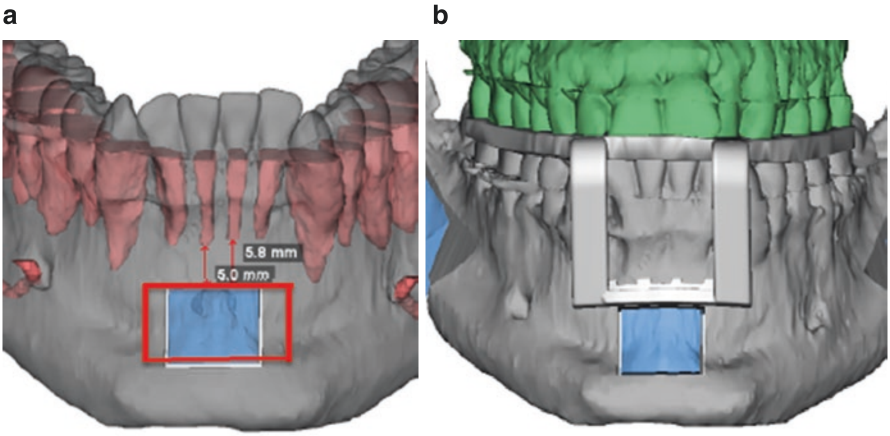

Fig. 8.3 (**a**) Example of a case where the superior aspect of the genial tubercle is 5 mm away from the lower incisor root apex. Further lateral extension (red outline) from the marked osteotomy lines enables greater muscle capture and facilitates bony overlap when rotating the rectangular window. (**b**) Example of a cutting guide to place the osteotomy just above the genial tubercles while clearing the mandibular incisor apices

genial tubercles and the incisor root apices are not considered good candidates for GGA. Preoperative planning includes osteotomy design and fabrication of cutting guides via rapid prototyping technology to ensure complete capture of the genioglossus muscle while decreasing the risk of neurosensory alterations, dental injury, and mandibular fracture (Fig. 8.3a, b).

8.6 Surgical Technique

Genioglossus advancement (GGA) is typically performed transorally. The mandibular anterior vestibule is injected with a local anesthetic containing epinephrine for hemostasis and to prevent surgical sensitization. With anterior traction on the lower lip, a mucosal incision is made approximately 10 mm below the mucogingival junction in the gingivolabial sulcus. This is carried out with a gentle smiling curve and extended to the distal aspect of the canine teeth. The incisions carried through mucosa, submucosa, and mentalis muscle and periosteum. An adequate cuff of mentalis muscle is left attached to proximal periosteum to facilitate soft tissue closure. Dissection is performed subperiosteally to expose the mandibular symphysis. Lateral dissection to expose the mental nerves is not required unless the osteotomy is carried to the inferior border posteriorly. [1, 14, 16, 17]

Prior to osteotomy, the mandible may be stabilized to the maxillary arch with maxillomandibular fixation (MMF) wires. If a cutting guide is used, this is inserted first and stabilized with MMF wires. The chosen osteotomy design is then performed with a sagittal saw and/or a reciprocating saw as needed under copious irrigation. Alternatively, a piezoelectric or ultrasonic handpiece with a straight blade may be used. The superior horizontal osteotomy should ideally be a minimum of 5 mm below the mandibular root apices to prevent incisor root injury, and if applicable, the inferior horizontal osteotomy should preserve the integrity of the inferior border to minimize the risk of fractures. A custom cutting guide based on the virtual plan is essential to predictably capture the genioglossus muscle and avoid damage to adjacent teeth. Since the canine roots are significantly more elongated relative to the incisors, the vertical bone cuts are made just medial to the canine tooth to avoid root injury. Before completing the osteotomy, a titanium screw is placed in the outer cortex to control and manipulate the bone flap (Fig. 8.4a–e). The full-thickness osteotomy should be completed with the sagittal saw instead of osteotomes and mallets

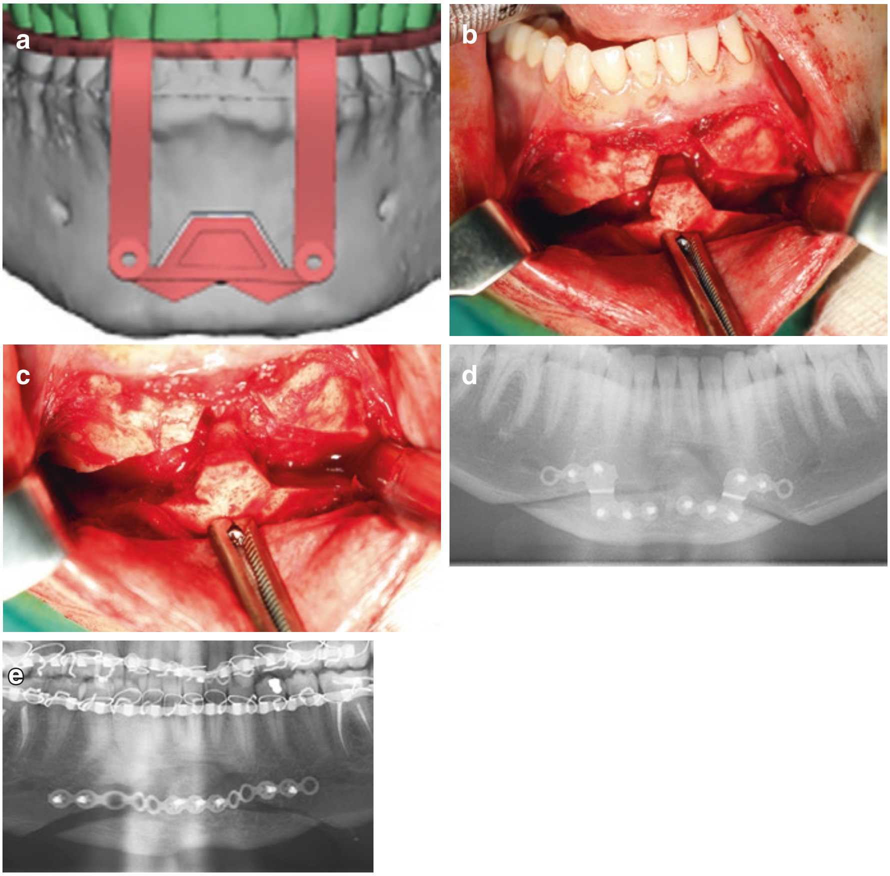

Fig. 8.4 (**a**) Virtually planned cutting guide allows precise placement of the superior osteotomy. (**b**) This case demonstrates a mortised genioplasty that includes lateral extensions to the inferior border as in a standard genioplasty. (**c**) Closer inspection reveals the genioglossus muscle attachment at the genial tubercle near the superior edge of the osteotomy. (**d**) Fixation may be achieved with two lateral plates and screws. (**e**) Alternative fixation method with a straight chain plate bent to adapt to the surrounding bones and overlying soft tissues

to avoid premature separation of the buccal cortex and marrow from the lingual cortex. In the window technique, the vertical and horizontal osteotomies should be parallel to each other. The osteotomized bony segment is delivered anteriorly by gentle traction until the lingual cortex including the insertion of genioglossus muscle reaches the anterior aspect of the mandible. The lingual aspect is inspected to confirm that the genioglossus muscle was captured in the bone flap.

The mandibular outer cortex and marrow of the repositioned segment are then removed using a reciprocating saw, while the lingual plate is stabilized with a bone-holding forceps. The osteotomized segment is then secured anteriorly using one of the methods described above.

After good hemostasis has been achieved, the surgical site is closed in two layers with the mentalis muscle resuspended with slowly absorbable sutures, and the mucosal edges are approximated with interrupted absorbable sutures on a tapered needle. A mentalis support dressing is adapted with elastic tape bandage, and light pressure is applied with a head wrap. This is used to prevent postoperative hematoma and lower lip or chin ptosis. The patient should be placed on a pureed to soft diet during the healing period.

8.7 Perioperative Complications

Depending on the technique adopted for GGA, several complications have been reported. These include mandibular fractures, injury and devitalization of adjacent mandibular teeth, neurosensory disturbances in the mental nerve distribution including dysesthesia, floor of mouth hematoma, infection, exposed hardware, unfavorable or unesthetic facial changes including lip ptosis, detachment of genioglossus muscle from the lingual plate, lack of improvement or worsening sleep parameters (AHI, minimum oxygen saturation, etc.), and lack of improvement in sleep quality and/or sleep-related symptoms.

8.8 Outcomes

One of the earliest studies employing GGA as a procedure to treat OSA was a review of 55 patients with OSA who were treated with GGA and hyoid myotomy with suspension (GAHM) [26]. They observed a response rate of 67% based on a mean reduction in RDI from 58.7 ± 23.4 to 11.8 ± 6.9. Since the introduction of GGA by Riley, the technique has undergone many modifications over the last 30 years to improve outcomes and limit complications [12–18]. However, the combination of GGA with other hypopharyngeal or oropharyngeal procedures is often necessary to adequately treat OSA, making direct comparisons between isolated procedures difficult. The majority of outcome studies on the effectiveness of GGA for the treatment of OSA have been limited to case series and retrospective studies (level four evidence). A review of literature shows success in the range between 40 and 70% where success is determined as postoperative respiratory disturbance index (RDI) less than 20 with at least a 50% reduction relative to the preoperative polysomnogram (known as Sher's success criteria) [7, 27–30].

Thus far, two systematic reviews have carried out a meta-analysis for outcomes of hypopharyngeal procedures in patients with OSA. In 2006, a meta-analysis by Kezirian and Goldberg [31] found success rates of genioglossal advancement to be between 39% and 78% after evaluating four case series totaling 91 cases [32–35]. Results of GGA as a sole procedure for treatment of hypopharyngeal obstruction in patients with severe OSA revealed a success rate of more than 60% in three studies [33–35]. Only two studies investigated lowest oxyhemoglobin saturation results [33, 35], and both showed improvement in low oxyhemoglobin saturation (LSAT). While there is evidence of improved outcomes with surgery, careful patient selection can significantly affect the success of treatment.

The second of the two systematic reviews evaluated the outcomes of various GGA techniques combined with hyoid surgery as treatment for OSA. Patients with hypoventilation syndrome or central sleep apnea and patients who lost more than 10% of their body weight between polysomnograms were excluded. Sher's surgical success criteria were used, and a surgical cure was defined as a postoperative AHI < 5 events/h. They identified 4 studies (45 patients) in which genioplasty was performed [36–39], 5 studies (24 patients) in which GTA was performed [18, 30, 32, 33, 40], and 4 studies (50 patients) in which genial tubercle advancement (GTA) with hyoid surgery was performed [1, 12, 26, 41]. A meta-analysis revealed four main findings. First, a comparison of the mean AHI before and after surgery demonstrated a reduction of 41.7% in patients with isolated GGA, 48.6% in patients who had genioplasty, and 57.4% in patients who underwent GGA with hyoid surgery. Second, LSAT scores in all studies showed an increase after surgery regardless of technique. Third, GTA demonstrated a greater improvement in AHI and LSAT following the procedure when compared to a genioplasty. The authors attributed a higher variability with genioplasty outcomes due to various modifications of technique allowing for different percentage of capture of the genial tubercles. The authors hypothesized that any technique that allows for complete capture of the genial tubercles and avoids excessive subperiosteal dissection of the inferior symphysis could result in similar outcomes to that of GTA. Fourth, although both GGA and genioplasty potentially increase the size of the upper airway by anteriorly displacing the tongue, the addition of hyoid surgery addresses another dimension of the obstruction, which is the reduction of the length of the upper airway. This lends further support to multilevel surgery compared to isolated procedures in OSA patients.

Hendler et al. achieved a success of 48% in their series of 33 patients who underwent the mortised genioplasty [16]. They observed patients with a BMI < 30 had a more successful outcome compared to patients with BMI > 30. Similarly, patients with preoperative AHI less than 50 had a more successful outcome (71%) compared to patients with a preoperative AHI greater than 50 (32%).

Kuscu and colleagues studied isolated GGA results for patients with a retrospective analysis and noted a 53% success rate based on AHI [30]. The authors also noted an improvement in ESS score and no significant difference between pre- and postoperative values of BMI and minimum O_2 saturation.

There is evidence that GGA may reduce hypersomnolence. A prospective randomized study by Thomas and colleagues comparing GGA with tongue-base suspension demonstrated a reduction in Epworth Sleepiness Scale (ESS) scores in the GGA group (eight patients) from a mean of 13.3 to 5.4. Airway collapse for five of eight patients measured on Muller maneuver improved by a mean of 75% at the base of the tongue [42].

Finally, while several studies have evaluated the effects of maxillomandibular advancement on the upper airway with 2D and 3D imaging, the influence of GGA on the airway remains poorly understood. In one Brazilian study of ten nonobese patients with mild to moderate OSA, baseline and postoperative posterior airway space (PAS) measurements were carried out on lateral cephalometric radiographs after GGA. A statistically significant increase in PAS from 7.9 ± 2.3 mm and 10.8 ± 2.5 mm was noted ($p < 0.001$). Moreover, this correlated with a reduction in AHI from 12.4 ± 4.6 to 4.4 ± 5.7 ($p < 0.001$) and a success rate of 70% [43]. While patients with airway narrowing seem to be good candidates for surgery, Johnson et al. noted that a narrower airway was associated with a smaller change in AHI, while patients with larger PAS had greater changes in AHI. They concluded that a smaller PAS was associated with treatment failure; however, their study was limited by a small sample size, a wide range of preoperative AHI, and an obese population [33]. Importantly, they were not able to identify any other predictive variables that correlated with change in AHI. In a critical assessment of responders and non-responders to GAHS, Riley and colleagues noted that non-responders ($n = 18$) had a higher incidence of chronic obstructive lung disease and greater mandibular retrognathia with a mean SNB angle of 75.5 ± 1.5 compared to the responder group (mean SNB 81 ± 2.0). Although they did not clarify what statistical methodology was used to determine the predictive value of COPD and SNB, they concluded that patients with normal skeletal development were better candidates for GAHS [26]. Implicit in this observation is the possible need for mandibular advancement in the presence of significant mandibular retrognathia.

Given the variability in response to surgery, a predictive tool akin to a CPAP titration would be quite beneficial. In one attempt to identify a predictive tool, Barrera et al. investigated the role of intraoperative bone flap tension and bicortical width of the mandible on surgical success of GGA. The authors measured the bicortical width of mandible at the genial tubercles intraoperatively and the force required to pull the osteotomized bony window forward with a tensiometer. Out of 18 patients, the authors found a 61.1% success rate. The variables of tension and bicortical width independently had no impact on postoperative outcomes. However, they noted a lower tension to width ratio was significantly associated with surgical response in their patients. Unfortunately, since the tension is determined intraoperatively, it cannot serve a predictive role in the preoperative setting [44].

8.9 Summary of Recommendations

Based on the available polysomnographic and surgical data, the following are general guidelines for the use of GGA surgery

1. A significant number of patients with severe OSA continue to have moderate to severe OSA (AHI >15) after GGA surgery. Patients with mild to moderate OSA have the highest success rate with GGA. MMA should be considered for patients with severe OSA.
2. Younger patients (<35) may have better airway soft tissue response and might experience higher success compared to older patients.
3. Patients with lower body weight, BMI <30, have better results with GGA.
4. The role of tongue size remains controversial. One study indicates that relative macroglossia predicts surgical success; however excess macroglossia or glossoptosis may predict poor outcomes with GGA.
5. Patients with microgenia may see a benefit in facial esthetics depending on the technique employed.
6. Patients with severe retrognathia (SNA <72) and significant upper airway narrowing may not respond to GGA but may be considered for MMA.
7. Due to substantial variability in the position of the genial tubercles, use of anatomical averages for GGA osteotomies may fail to capture the whole muscle attachment and increases the risk of damage to adjacent dentition. The use of virtual surgical planning can help determine suitable candidates for the procedure and allow for accurate capture of the tubercles and muscle complex.

8.10 Summary

Genioglossus advancement is a technique-sensitive procedure that requires a tailored approach using virtual surgical planning and 3D printed cutting guides to identify an isolated tubercle instead of relying on averages. The authors feel genioglossus advancement has a role as an adjunctive procedure in conjunction with MMA, as well as other retropharyngeal and retropalatal procedures. However, both as an adjunctive procedure and on its own, its true value in long-term and short-term reduction of AHI and improvement of sleep parameters is yet to be fully determined.

Based on the evidence so far, an ideal patient for GGA would be a young patient who is not obese, has mild to moderate OSA, and does not have significant airway compromise related to macroglossia, retrognathia, or neuromuscular tone involvement.

References

1. Riley R, Guilleminault C, Powell N, Derman S. Mandibular osteotomy and hyoid bone advancement for obstructive sleep apnea: a case report. Sleep. 1984;7:79–82.
2. Sauerland EK, Harper RM. The human tongue during sleep: electromyographic activity of the genioglossus muscle. Exp Neurol. 1976;51:160–70.
3. Lo YL, Jordan AS, Malhotra A, et al. Genioglossal muscle response to CO_2 stimulation during NREM sleep. Sleep. 2006;29:470–7.
4. Bianchi AL, Denavit Saubie M, Champagnat J. Central control of breathing in mammals: neuronal circuitry, membrane properties, and neurotransmitters. Physiol Rev. 1995;75:1–45.

5. Stanchina ML, Malhotra A, Fogel RB, et al. The influence of lung volume on pharyngeal mechanics, collapsibility, and genioglossus muscle activation during sleep. Sleep. 2003;26:851–6.
6. Fujita S. Pharyngeal surgery for obstructive sleep apnea and snoring. In: Fairbanks DNF, et al., editors. Snoring and obstructive sleep apnea. New York: Raven Press; 1987. p. 101–28.
7. Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. Sleep. 1996;19(2):156–77.
8. Silverstein K, Costello BJ, Giannakpoulos H, Hendler B. Genioglossus muscle attachments: an anatomic analysis and the implications for genioglossus advancement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;90:686–8.
9. Mintz SM, Ettinger AC, Geist JR, Geist RY. Anatomic relationship of the genial tubercles to the dentition as determined by cross-sectional tomography. J Oral Maxillofac Surg. 1995;53:1324–6.
10. Bell WH, Proffit WR, White RP. Surgical correction of dentofacial deformities. 1st ed. Philadelphia, PA: Saunders; 1980. p. 1218–26.
11. Zhang X, Bell WH, Washko PW. Relationship of mandibular anterior tooth apices to genial muscle attachments. Oral Surg Oral Med Oral Pathol. 1988;65:653.
12. Riley R, Powell N, Guilleminault C. Inferior sagittal osteotomy of the mandible with hyoid myotomy-suspension: a new procedure for obstructive sleep apnea. Otolaryngol Head Neck Surg. 1986;94:589–93.
13. Riley RW, Powell NB, Guilleminault C. Obstructive sleep apnea syndrome: a review of 306 consecutively treated surgical patients. Otolaryngol Head Neck Surg. 1993;108:117–25.
14. Dattilo DJ. The mandibular trapezoid osteotomy for the treatment of obstructive sleep apnea: report of a case. J Oral Maxillofac Surg. 1998;56:1442–6.
15. Lee NR, Woodson BT. Genioglossus muscle advancement via a trephine osteotomy approach. Oper Tech Otolaryngol Head Neck Surg. 2000;11(50):50–4.
16. Hendler BH, Costello BJ, Silverstein K, et al. A protocol for uvulopalatopharyngoplasty, mortised genioplasty, and maxillomandibular advancement in patients with obstructive sleep apnea: an analysis of 40 cases. J Oral Maxillofac Surg. 2001;59:892–7.
17. Demian NM, Alford J, Takashima M. An alternative technique for genioglossus muscle advancement in phase I surgery in the treatment of obstructive sleep apnea. J Oral Maxillofac Surg. 2009;67(10):2315–8.
18. Garcia Vega JR, de la Plata MM, Galindo N, et al. Genioglossus muscle advancement: a modification of the conventional technique. J Craniomaxillofac Surg. 2014;42(3):239–44.
19. Hsu PP, Tan BY, Chan YH, et al. Clinical predictors in obstructive sleep apnea patients with computer assisted quantitative video endoscopic upper airway analysis. Laryngoscope. 2004;114:791–9.
20. Terris DJ, Hanasono MM, Liu YC. Reliability of the Muller maneuver and its association with sleep disordered breathing. Laryngoscope. 2000;110:1819–23.
21. Schendel S. The airway assessment of the patient with obstructive sleep apnea. In: Surgical enhancement of orthodontic treatment, vol. 47. Craniofacial Growth Series. Ann Arbor, MI: University of Michigan; 2009. p. 203–30.
22. Yamashina A, Tanimoto K, Sutthiprapaporn P. The reliability of computed tomography (CT) values and dimensional measurements of the oropharyngeal region using cone beam CT comparison with multivector CT. Dent Maxillofac Radiol. 2008;37:245.
23. Li HY, Chen NH, Wang CR, Shu YH, Wang PC. Use of three-dimensional computed tomography scan to evaluate upper airway patency for patients undergoing sleep-disordered breathing surgery. Otolaryngol Head Neck Surg. 2003;129(4):336–42.
24. Liu SY-C, Huon L-K, Zaghi S, Riley R, Torre C. An accurate method of designing and performing individual-specific genioglossus advancement. Otolaryngol Head Neck Surg. 2017;156(1):194–7.
25. Hueman EM, Noujeim ME, Langlais RP, Prihoda TJ, Miller FR. Accuracy of cone beam computed tomography in determining the location of the genial tubercle. Otolaryngol Head Neck Surg. 2007;137(1):115–8.

26. Riley RW, Powell NB, Guilleminault C. Inferior mandibular osteotomy and hyoid myotomy suspension for obstructive sleep apnea: a review of 55 patients. J Oral Maxillofac Surg. 1989;47:159–64.
27. Ramirez SG, Loube DI. Inferior sagittal osteotomy with hyoid bone suspension for obese patients with sleep apnea. Arch Otolaryngol Head Neck Surg. 1996;122(9):953–7.
28. Vilaseca I, Morello A, Montserrat JM, et al. Usefulness of uvulopalatopharyngoplasty with genioglossus and hyoid advancement in the treatment of obstructive sleep apnea. Arch Otolaryngol Head Neck Surg. 2002;128(4):435–40.
29. Riley RW, Powell NB, Guilleminault C. Obstructive sleep apnea syndrome: a surgical protocol for dynamic upper airway reconstruction. J Oral Maxillofac Surg. 1993;51(7):742–7.
30. Kuscu O, Suslu AE, Ozer S, Gunaydin RO, Ogretmenoglu O, Onerc IM. Sole effect of genioglossus advancement on apnea hypopnea index of patients with obstructive sleep apnea. Acta Otolaryngol. 2015;135:835–9.
31. Kezirian EJ, Goldberg AN. Hypopharyngeal surgery in obstructive sleep apnea: an evidence-based medicine review. Arch Otolaryngol Head Neck Surg. 2006;132(2):206–13.
32. Riley RW, Powell NB, Guilleminault C. Obstructive sleep apnea and the hyoid: a revised surgical procedure. Otolaryngol Head Neck Surg. 1994;111:717–21.
33. Johnson NT, Chinn J. Uvulopalatopharyngoplasty and inferior sagittal mandibular osteotomy with genioglossus advancement for treatment of obstructive sleep apnea. Chest. 1994;105:278–83.
34. Lee NR, Givens CD Jr, Wilson J, Robins RB. Staged surgical treatment of obstructive sleep apnea syndrome: a review of 35 patients. J Oral Maxillofac Surg. 1999;57:382–5.
35. Miller FR, Watson D, Boseley M. The role of the Genial Bone Advancement Trephine system in conjunction with uvulopalatopharyngoplasty in the multilevel management of obstructive sleep apnea. Otolaryngol Head Neck Surg. 2004;130:73–9.
36. Krekmanov L, Andersson L, Ringqvist M, et al. Anterior–inferior mandibular osteotomy in treatment of obstructive sleep apnea syndrome. Int J Adult Orthodon Orthognath Surg. 1998;13:289–98.
37. Santos JF Jr, Abrahao M, Gregorio LC, Zonato AI, Gumieiro EH. Genioplasty for genioglossus muscle advancement in patients with obstructive sleep apnea-hypopnea syndrome and mandibular retrognathia. Braz J Otorhinolaryngol. 2007;73:480–6.
38. Tabrizi R, Pourdanesh F, Soleimanpour M, Shafie E. Evaluation of mandibular wing osteotomy in obstructive sleep apnea cases with retrognathia. J Maxillofac Oral Surg. 2015;14:46–50.
39. Yin W, Feng S, Guan W. Mandibular advancement for the treatment of micrognathia with obstructive sleep apnea. Zhonghua Zheng Xing Shao Shang Wai Ke Za Zhi. 1994;10:265–9.
40. Foltan R, Sonka K. [Genioglossal advancement in the surgical treatment of obstructive sleep apnea syndrome in adults]. Sb Lek. 2000; 101:393–8.
41. Foltan R, Hoffmannova J, Pretl M, Donev F, Vlk M. Genioglossus advancement and hyoid myotomy in treating obstructive sleep apnoea syndrome: a follow-up study. J Craniomaxillofac Surg. 2007;35:246–51.
42. Thomas AJ, Chavoya M, Terris DJ. Preliminary findings from a prospective, randomized trial of two tongue-base surgeries for sleep-disordered breathing. Otolaryngol Head Neck Surg. 2003;129(5):539–46.
43. Santos Junior JF, Abrahao M, Gregorio LC, Zonato AL, Gummieiro EH, et al. Genioplasty for genioglossus advancement in patients with obstructive sleep apnea hypopnea syndrome and mandibular retrognathia. Braz J Otorhinolaryngol. 2007;73(4):480–6.
44. Barrera JE, Dion GR. Predicting surgical response using tensiometry in OSA patients after genioglossus advancement with uvulopalatopharyngoplasty. Otolaryngol Head Neck Surg. 2016;154(3):558–63.