Clinical Oral Investigations (2020) 24:1359–1367
https://doi.org/10.1007/s00784-019-03017-5

ORIGINAL ARTICLE

Optimizing mandibular sagittal split of large maxillomandibular advancements for obstructive sleep apnea: patient and surgical factors

Yu Feng Chen [1,2,3] • Edward Chengchun Ko [2,3] • Soroush Zaghi [1,4] • Audrey Yoon [1,5] • Ryan Williams [1] • Robert Riley [1] • Stanley Yung-Chuan Liu [1]

Received: 18 December 2018 / Accepted: 10 July 2019 / Published online: 22 July 2019

Abstract

Objectives Maxillomandibular advancement (MMA) confers consistent and high rates of surgical success for obstructive sleep apnea (OSA). In the era of value-based medicine, identifying factors that affect the stability of rigid fixation and allow rapid return to function are important targets for improvement. The aim of this study was to identify patient and surgical factors associated with mandibular sagittal split outcomes associated with optimal postoperatively skeletal stability.

Study design Retrospective cohort study.

Materials and methods Forty-six subjects (43 males and 3 females) with postoperative CT scans including three-dimensional reconstruction from which mandibular split patterns could be analyzed were enrolled. Patient factors (age and polysomnographic measures) and surgical factors (extent of osteotomy prior to controlled fracture) were assessed. Outcome measures include (1) bone thickness for rigid fixation and (2) area of passive bony overlap after advancement.

Results Age and severity of disease did not contribute significantly to optimal mandibular split patterns. For optimal area for passive bony overlap and thickness of buccal and lingual plates for rigid fixation, the most important factors are related to surgical technique.

Conclusions Anterior osteotomy just to the midline of inferior border and horizontal osteotomy to the mandibular foramen are associated with split patterns that result in optimal rigid fixation and passive bony overlap for OSA patients undergoing MMA.

Clinical relevance Optimal surgical technique has the most significant influence in allowing rapid return to function after MMA in patients with OSA.

Keywords Maxillomandibular advancement · Obstructive sleep apnea · Sagittal split osteotomy · Rigid fixation · Value-based medicine · Snoring · Mandibular fracture

✉ Stanley Yung-Chuan Liu
ycliu@stanford.edu

1 Division of Sleep Surgery, Department of Otolaryngology-Head & Neck Surgery, Stanford University School of Medicine, 801 Welch Road, Standford, CA 94305, USA

2 Division of Oral and Maxillofacial Surgery, Kaohsiung Medical University Hospital, No. 100 Tzyou 1st Road, Kaohsiung 80708, Taiwan

3 School of Dentistry, College of Dental Medicine, Kaohsiung Medical University, No. 100 ShihChuan 1st Road, Kaohsiung 80708, Taiwan

4 UCLA Santa Monica medical Center, 1250 16th St, Santa Monica, CA 90404, USA

5 Department of Pediatric Dentistry, UCLA School of Dentistry, 10833 Le Conte Ave, CHS 20-137, Los Angeles, CA 90095, USA

Introduction

Maxillomandibular advancement (MMA) confers consistent and high rates of surgical success for obstructive sleep apnea (OSA) [1, 2]. Two large meta-analysis and systematic reviews report success and cure rates around 86% and 43%, respectively. Dynamic assessment with sleep endoscopy shows that advancement with counterclockwise rotation of the maxillomandibular complex result in airway stability via stabilization of the velum and lateral pharyngeal wall [3, 4]. Classically, the postoperative recovery can be lengthy as the mandible regains adequate strength for proper mastication and speech function. In the era of value-based outcome optimization, factors that contribute to a faster return to function are important targets of improvement for any surgical intervention [5, 6].

An important factor that allows faster return to baseline mandibular function in MMA surgery is postoperative skeletal stability. This is influenced by the osteotomy and controlled fracture performed during the sagittal split procedure [7, 8]. MMA uniquely demands significant advancement and counterclockwise rotation of the jaw complex. Inadequate thickness of overlapping bone does not allow optimal rigid fixation. Inadequate area of passive bony contact increases the risk of postoperative fracture.

Beyond surgical challenges, systemic inflammation from chronic, intermittent hypoxia in OSA patients affects bone metabolism. Severe OSA male patients have been reported to have lower bone marrow density than non-OSA patients [9]. Active pathological bone destruction often occur at sites where oxygen tension is low, and hypoxia stimulates activation of precursor cells to osteoclasts [10]. Age has also been implicated in a higher incidence of suboptimal mandibular fracture patterns during sagittal split in orthognathic surgery [11]. Patients undergoing MMA on average are even older than orthognathic surgery patients.

The aim of our study is to identify patient and surgical factors associated with mandibular sagittal split patterns that influence (1) bone thickness for rigid fixation and (2) passive area of bony overlap.

Methods

Study design

This is a retrospective cohort study of OSA subjects who underwent MMA in the Sleep Surgery Division (S.Y.C.L., R.W.R.) of the Department of Otolaryngology at Stanford University. Eighty-two subjects underwent MMA from July 2013 to July 2016. Forty-six subjects (43 males and 3 females) who obtained postoperative CT scan with three-dimensional reconstruction from which mandibular split patterns could be analyzed were enrolled. The Institutional Review Board of Stanford University approved the study (Protocol 29182, IRB # 6208).

Data collection

All maxillofacial imaging was obtained while the patient was in supine position (CT slice thickness, 0.625 mm) on postoperative day 1 or 2. CT data was exported in DICOM format and rendered to bone surface representations by the Stanford 3D and Quantitative Imaging Laboratory.

The following patient factors were collected: age, body mass index (BMI), Apnea-Hypopnea Index (AHI), oxygen desaturation index (ODI), respiratory disturbance index (RDI), and lowest oxygen saturation level (LSAT).

Two surgeons blinded to the demographic and polysomnographic factors rated the CT scans to assess the pattern of osteotomy and sagittal split outcomes.

Surgical technique

Two experienced surgeons (SYCL, RWR) performed all mandibular split procedures as previously published [12]. The original sagittal split described by Obwegeser takes the horizontal osteotomy through the full anterior-posterior dimension of the ramus (Fig. 1a). The Hunsuck modification terminates the horizontal osteotomy at the mandibular foramen (Fig. 1b), which is the more contemporary method of performing mandibular sagittal splits. The optimal Hunsuck modification of the sagittal split results in a controlled fracture where the dentate segment includes a substantial area of the medial ramus and part of the angle.

After the osteotomies are made, the sagittal split begins with a straight osteotome directed towards the mandibular foramen. The anterior split begins by the use of three straight osteotomes that gently wedge open the anterior border of the proximal segment. Repeatedly throughout

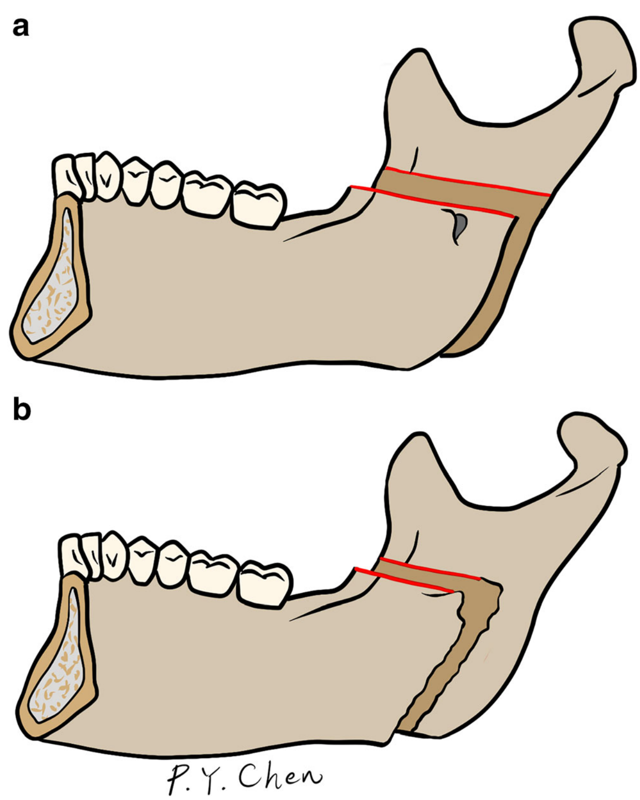

Fig. 1 Evolution of the mandibular sagittal split osteotomy. **a** The sagittal split first described by Obwegeser. The horizontal osteotomy is performed through the full thickness of the medial ramus. **b** The modification of the sagittal split described by Hunsuck. The termination of horizontal osteotomy at the mandibular foramen allows improved consistency of controlled fracture

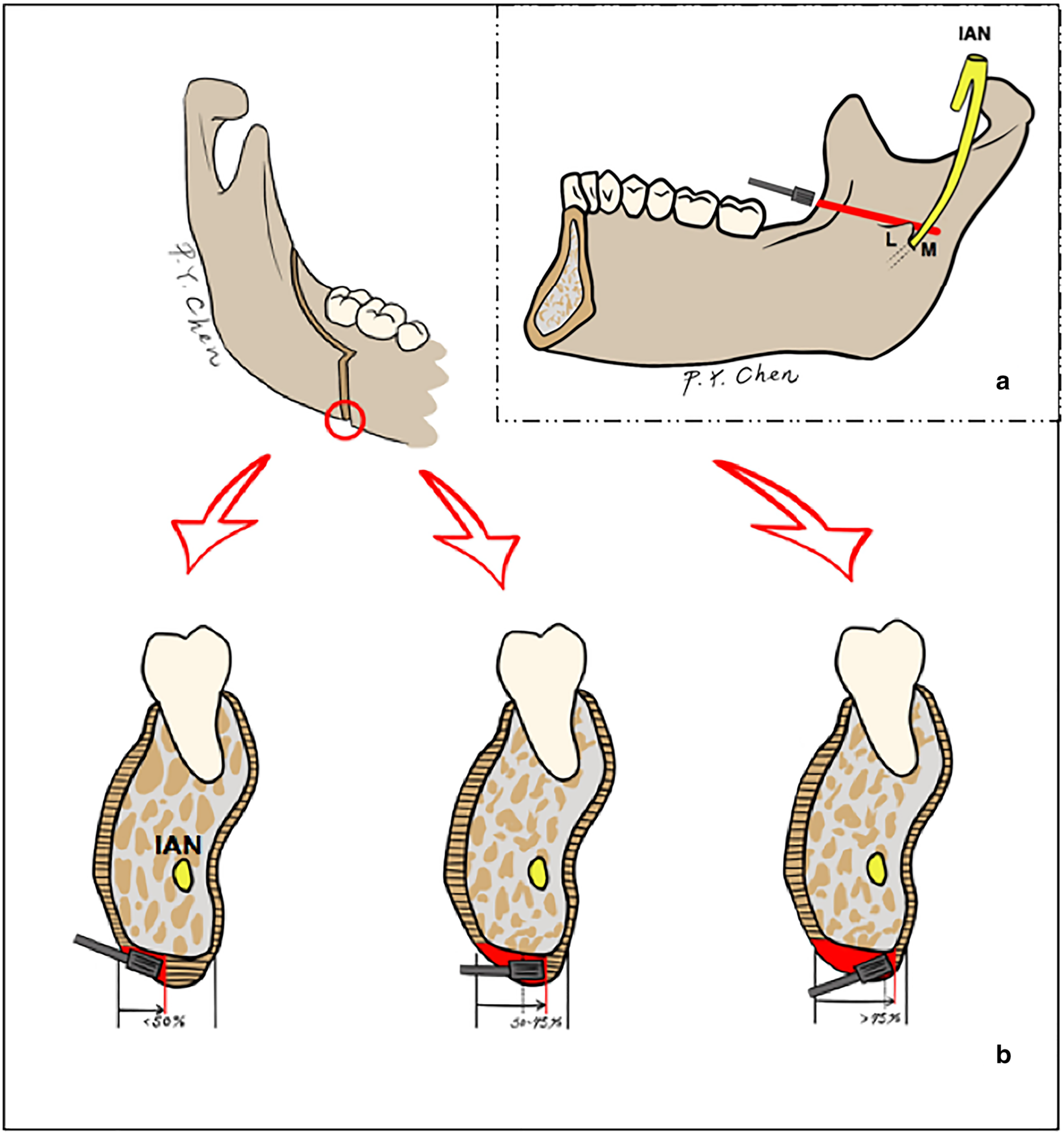

Fig. 2 Surgical factors assessed for optimal fracture patterns for OSA patients undergoing maxillomandibular advancement. (A) Horizontal osteotomy through the mandibular foramen. (B) Anterior osteotomy at the inferior border. Categories are defined as less than 50% (50% is the midline), 50~75% (past midline towards the lingual cortex), over than 75% (past midline towards the lingual cortex). L, lingula; M, mandibular foramen; IAN, inferior alveolar nerve

this process, separation from the inferior border of the mandible is observed. This is to "open like a book" gently, rather than only the superior border open, but the inferior border fixed.

For fixation, two to three bicortical screws are used in the ascending body and ramus area, combined with a long 2.4-mm plate with monocortical screws across the advancement gap.

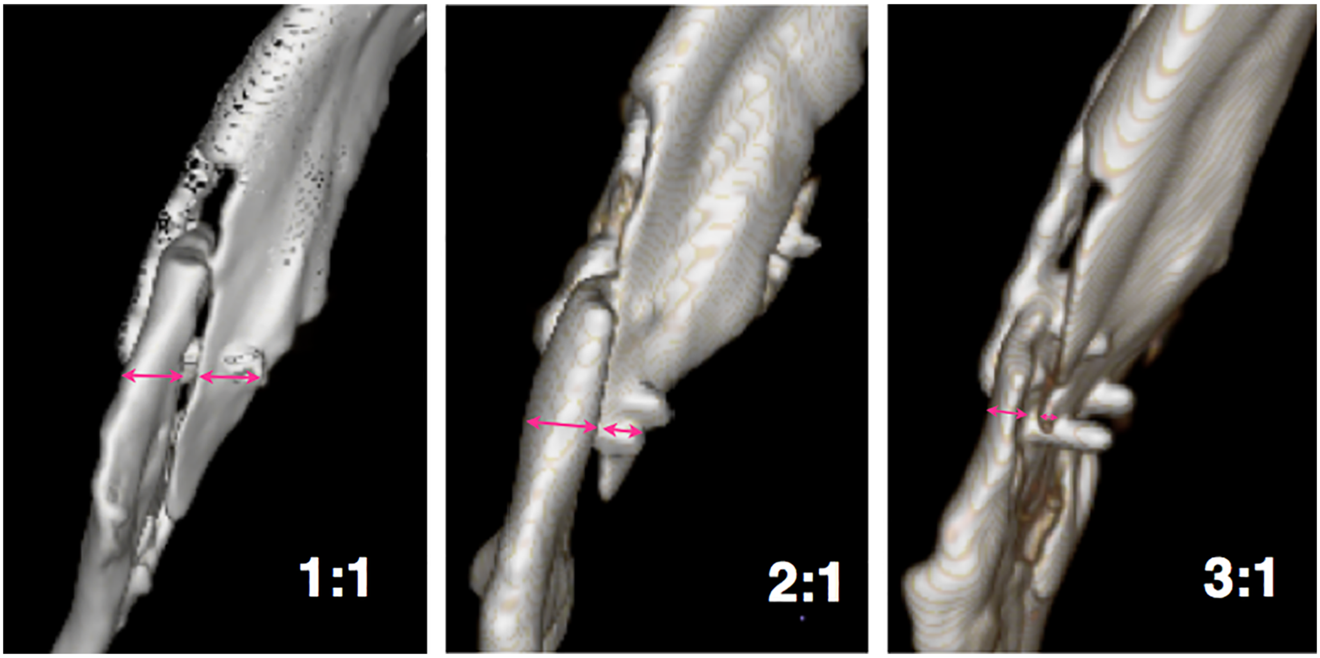

Fig. 3 Sagittal split outcome assessment: ratio of buccal and lingual plate thickness for rigid fixation

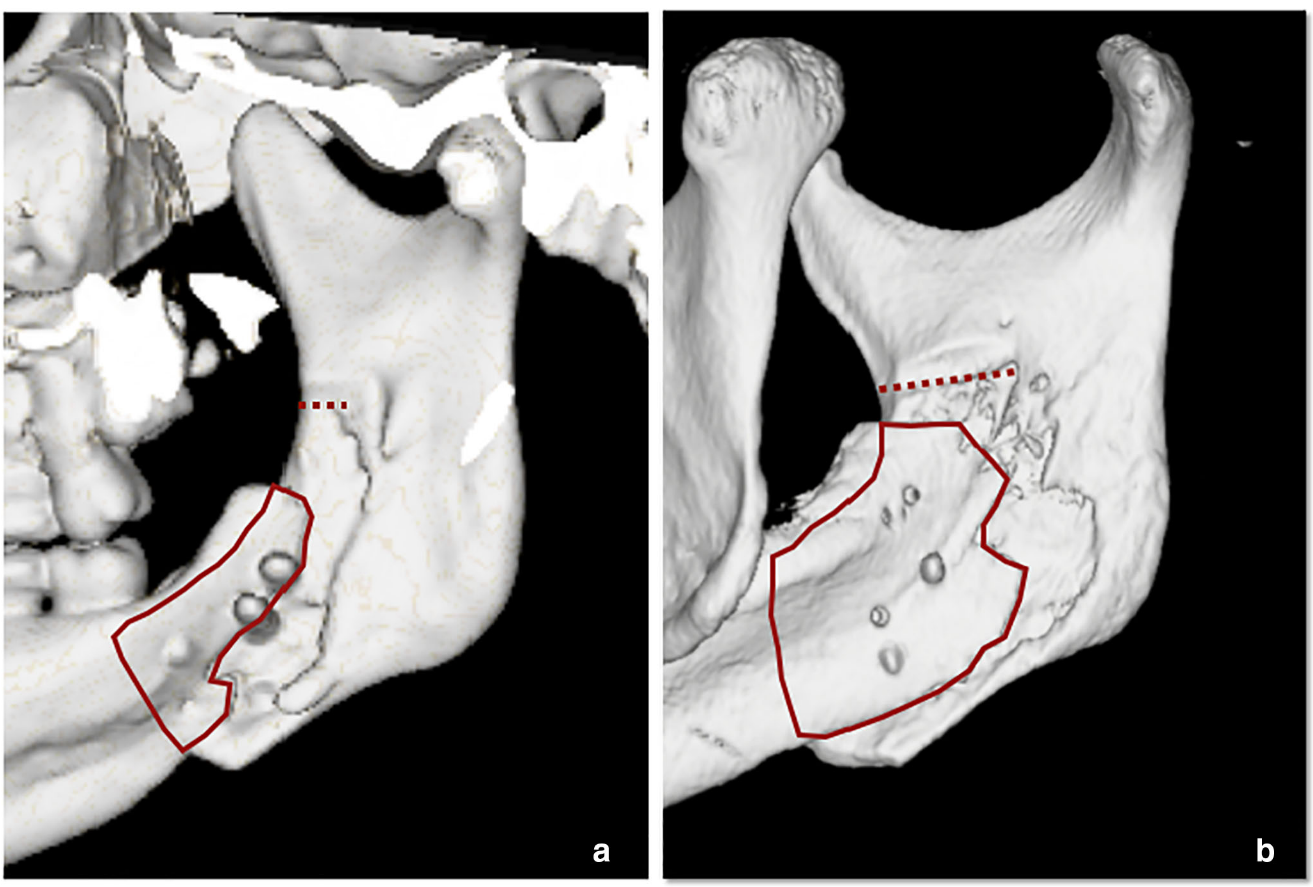

Fig. 4 Sagittal split outcome assessment: area for passive bony contact after large advancement. **a** Suboptimal area of contact: fracture resulting in passive overlap of the condylar and dentate segments only at the posterior body of the mandible. **b** Optimal area of contact: passive overlap of condylar and dentate segments including large area of the ramus and part of the angle

Table 1 Patient factors($N = 46$, males = 43)

Age	40.1 ± 11.5
BMI	30.4 ± 10.7
AHI	42.6 ± 25.3
ODI	36.8 ± 28.1
RDI	44.8 ± 25.2
LSAT	82.0 ± 8.6

BMI body mass index, *AHI* Apnea-Hypopnea Index, *ODI* oxygen desaturation index, *RDI* respiratory desaturation index, *LSAT* lowest saturation of oxygen

Patients generally are not in intermaxillary fixation postoperatively, only light guiding elastics are used after surgery.

Surgical factors

1. Completion of the ramus horizontal osteotomy to the mandibular foramen (Fig. 2(A)).
2. Extent of anterior osteotomy at the inferior border of the mandible: less than the midline (50%), beyond the midline towards the lingual (50–75%), and greater than 75% towards the lingual (Fig. 2(B)).

Outcome measures

1. Buccal and lingual plate thickness for rigid fixation. Buccal and lingual plate thickness were measured at the level of the bicortical screw. Buccal to lingual plate thickness were categorized as ratios of 1:1, 2:1, or 3:1 (Fig. 3). Of these categories, the most optimal is the 1:1, where the bicortical screw is embedded equally in the split buccal and lingual cortices. The least optimal is the 3:1, where the lingual cortex is significantly thinner than the buccal. This can lead to fractures of the lingual cortex unnoticed by the operator intra-operatively, or fractures postoperatively.

Table 2 Distribution of osteotomies assessed as predictors of sagittal split outcomes

	($N = 92$)	
	N	%
Anterior osteotomy at inferior border		
< 50%	49	53.8
50~75%	15	16.5
> 75%	27	29.7
Horizontal osteotomy to mandibular foramen		
No	29	31.9
Yes	62	68.1

50% denotes the midline of the inferior border. 50 to 75% denotes the extent of osteotomy past the midline and towards the lingual cortex

Table 3 Distribution of sagittal split outcomes

	($N = 92$)	
	N	%
Ratio of buccal and lingual plate thickness for rigid fixation		
1:1	25	27.5
2:1	31	34.1
3:1	35	38.4
Area of passive bony overlap		
Sufficient	63	68.9
Insufficient	28	31.1

See Fig. 2(A, B) for the description of sagittal split outcomes

2. Area of mandibular bony overlap (Fig. 4). Inadequate bony contact is considered when the fracture pattern begins before the mandibular foramen and traverses anteriorly. In Fig. 4a, the area of passive contact between the condylar and dentate segments is limited to mostly the body of the mandible. Contrast this with Fig. 4b, where the fracture propagates inferiorly, capturing the ramus and part of the angle to maximize overlap after mandibular advancement.

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 22.0 for Mac; SPSS Inc. Chicago, IL, USA). Continuous variables are summarized as mean ± SD. As all factors were assessed per side of the mandible, mixed models were adjusted to account for the correlated nature of the right and left side measurements. Univariate with chi-square or independent t test was performed to assess the influence of surgical and patient factors. Post hoc multivariate analysis (logistical regression with random effects) was used to assess the covariates. Two-tailed p value < 0.05 was considered statistically significant.

Results

Forty-six subjects (43 males and 3 females) with OSA who underwent MMA and obtained postoperative CT reconstructions were analyzed. Demographic and polysomnographic data are summarized in Table 1. Age at time of MMA ranged from 19 to 62 years (mean age 40.1 ± 11.5). Mean BMI was

Table 4 Factors influencing buccal and lingual plate thickness for rigid fixation

Ratio of buccal and lingual plate thickness		1:1 ($n = 25$)	2:1 ($n = 31$)	3:1 ($n = 35$)	Univariate analysis	Multivariate model
Horizontal osteotomy through the mandibular foramen	Yes ($n = 62$)	(21) 33.9%	(23) 37.1%	(18) 29.0%	$p = 0.019$	$p = 0.018$
	No ($n = 29$)	(4) 13.8%	(8) 27.6%	(17) 58.6%		
Anterior osteotomy at the inferior border of the mandible	<50% ($n = 49$)	(19) 38.8%	(19) 38.8%	(11) 22.5%	$p = 0.008$	$p = 0.006$
	50–75% ($n = 15$)	(3) 20.0%	(5) 33.3%	(7) 46.7%		
	> 75% ($n = 27$)	(3) 11.1%	(7) 25.9%	(17) 63.0%		

Both horizontal osteotomy to the mandibular foramen and extent of anterior inferior border osteotomy were significantly associated with the ratio of buccal and lingual plate thickness

30.4 ± 10.7, AHI was 42.6 ± 25.3, ODI was 36.8 ± 28.1, RDI was 44.8 ± 25.2, and LSAT was 82.0 ± 8.6. Surgical success rate in this group was 89.5%, with postoperative polysomnographic results: AHI 9.4 ± 5.1, ODI 6.9 ± 4.5, RDI 11.0 ± 3.9, LSAT 89.1 ± 3.5.

In 92 mandibular sagittal split osteotomies, surgeons performed a horizontal osteotomy to the mandibular foramen 68.1% of the time. The anterior osteotomy was extended past the midline of the inferior border 31.9% of the time (Table 2).

For rigid fixation after sagittal split osteotomy, thickness of the buccal and lingual plates was broken down as follows: (1) 1:1 ratio, 27.5%; (2) 2:1 ratio, 34.1%; and (3) 3:1 ratio, 38.4%. For the area of passive bony contact, 68.9% was adequate (split included ramus and part of the angle of the mandible) (Table 3). In the passive and adequate bony contact group, the breakdown was (1) 1:1 ratio, 37.1%; (2) 2:1 ratio, 38.7%; and (3) 3:1 ratio, 24.2%.

There was strong agreement with intra- and inter-rater variability. Kappa statistics showed the level of agreement to be 0.952 and 0.894, respectively.

Both osteotomy to the mandibular foramen and the extent of anterior inferior border osteotomy were significantly associated with outcome of the buccal and lingual plate thickness. There was a higher likelihood of resulting in 3:1 thickness when the osteotomy did not pass through the mandibular foramen and when the anterior osteotomy was taken past the midline and > 75% towards the lingual cortex (Table 4).

There is a 43.7 odds ratio (95% confidence interval, 12.1–157.5) of obtaining adequate area of passive bony overlap when the horizontal osteotomy is made to the mandibular foramen ($p < 0.0001$) (Table 5).

Horizontal osteotomy to the mandibular foramen (OR = 14.3, 95% CI 1.8–112.8, $p = 0.0016$) and anterior osteotomy to the midline of the inferior border ($p = 0.027$) significantly improve the odds of an optimal sagittal split outcome for MMA characterized by (1) 1:1 buccal to lingual plate thickness for rigid fixation and (2) adequate area of passive bony overlap. These surgical factors are significant in both univariate and multivariate analyses. Patient factors are not significantly associated with optimal sagittal split outcome (Table 6).

Table 5 Factor influencing area of passive bony overlap

Adequate area of bony overlap		Yes	No	Total
Osteotomy through the mandibular foramen	Yes	(57) 91.9%	(5) 8.0%	(62) 100%
	No	(6) 20.7%	(23) 79.3%	(29) 100%
	Total	(63)	(28)	(91)

There is adequate area of passive bony overlap in 91.9% of cases where the osteotomy passes through the mandibular foramen. There is a 43.7 odds ratio (95% confidence interval, 12.1–157.5) of improved chances of adequate area of passive bony overlap when the osteotomy is performed to pass through the mandibular foramen ($p < 0.0001$)

Table 6 Factors associated with ideal sagittal split pattern for maxillomandibular advancement

		Ideal sagittal split pattern for large mandibular advancement					
		Yes ($n = 22$)	No ($n = 69$)	Odds ratio	95% confidence interval	Univariate analysis	Multivariate model
Osteotomy through the mandibular foramen	Yes ($n = 62$)	(21) 33.9%	41 66.1%	14.3	(1.8–112.8)	$p = 0.0016$	$p = 0.0005$
	No ($n = 29$)	(1) 3.5%	(28) 96.5%				
Anterior osteotomy at the inferior border of the mandible	< 50% ($n = 49$)	17 34.7%	32 65.3	N/A	N/A	$p = 0.0268$	$p = 0.0202$
	50–75% ($n = 15$)	3 20.0%	12 80.0%				
	> 75% ($n = 27$)	2 7.4%	25 92.3%				
Age (mean ± SD)		42.1 ± 27.1	42.5 ± 24.8	N/A	N/A	$p = 0.9407$	N/A
AHI (mean ± SD)		36.7 ± 12.5	41.0 ± 11.0	N/A	N/A	$p = 0.1221$	N/A

There is a 14.3 odds ratio (95% confidence interval, 1.8–112.8) of improved chances of adequate passive bony overlap when the horizontal osteotomy is through to the mandibular foramen ($p = 0.0016$). The odds of having a 1:1 ratio of buccal to lingual plate thickness for rigid fixation is improved when the anterior osteotomy is made just to the midline of inferior border ($p = 0.0268$). Surgical factors are found to be independent predictors of ideal sagittal split scenario for MMA with multivariate analysis. Age and AHI were not found to be statistically significant covariates

Discussion

Beyond the well-reported efficacy of maxillomandibular advancement (MMA) as a surgical treatment for OSA, less academic effort has been focused on identification of factors that lead to more rapid recovery to increase value-based outcomes. As rapid return to eating and talking are significant concerns for patients, maximizing skeletal stability postoperatively for optimal healing should be a surgical priority. This study is dedicated to the identification of factors leading to optimal mandibular sagittal splits, specifically in patients with OSA who tend to be older and most severely affected by comorbidities of OSA.

Currently at Stanford, our protocol typically involves a 2-week postoperative period when the patient's jaws are placed in a limited number of elastic bands. Jaws are never wired shut, nor are they so heavily banded such that the mouth cannot open. MMA patients tend to be older, and the degree of nasal obstruction after maxillary osteotomy is bothersome. Allowing the patients to breathe through the mouth for the first 2 weeks significantly improves comfort. Most patients discontinue narcotic pain medications by the end of second week. Patients start on pureed diet on the third week, and from that point on, they go through a weekly progression from soft to regular diet. The postoperative protocol can vary greatly among institutions and over time. Even at Stanford, until recently in the last 5 years, patients were classically placed in maxillomandibular fixation for up to 6 weeks. While this conservative measure is consistent with treatment of jaw fracture patients, we believe that optimizing the mandibular split can safely allow some patients to progress at the more rapid rate described.

Findings from this study suggest that for significant advancements of the mandible, the anterior osteotomy should not be carried past the midline. This would allow increased odds of a 1:1 buccal to lingual plate thickness ratio for rigid fixation. For increased area of passive bony overlap, the Hunsuck modification needs to be performed consistently. This is consistent with findings from orthognathic surgery, where three-dimensional reconstructed images show that a sufficient area for passive bony overlap is increased with horizontal osteotomy carried to the mandibular foramen [13]. While the lingula can be reliably found during surgery, the exact location of the mandibular foramen is more variable, as it is posterior to the lingula at different distances. Efforts should be made to visualize the mandibular foramen to direct the osteotomy accordingly. This can be performed with endoscopic visualization using a 70-degree scope or extending the osteotomy with a blunt osteotome by a few extra millimeters past the lingula. In the blind technique, great care needs to be taken to not traverse through and through the ramus.

The orthognathic surgery literature tends to advise surgeons to carry the anterior osteotomy past the midline of the inferior mandible [14]. This is logical as it allows for an easier split with a thin lingual plate. This is especially helpful if one is performing a mandibular setback. However, a thin lingual plate does not allow adequate bone thickness for rigid fixation with bicortical screws in large advancements. If this is combined with inadequate passive bony overlap, slower return to function can be expected, with malunion or pathologic fracture at increased risk. Of the 82 subjects who underwent MMA during the study period, one subject presented with this unfavorable combination and sustained a postoperative jaw fracture.

It is encouraging to find that patient age or severity of OSA did not contribute significantly to the operative outcome of sagittal split osteotomy. There are reports correlating age and unfavorable splits in the orthognathic literature, where the mid-thirties tend to be the threshold for a difference in outcomes [11, 15]. Typically, OSA patients undergoing MMA are twice the age of the routine orthognathic surgery patient. Our findings demonstrate that as compared to age or severity of OSA, surgical techniques correlate much more strongly with optimal mandibular split patterns that influence postoperative stability and rapid return to function.

Of the subjects included in the study, one subject required earlier removal of hardware and debridement for a buccal plate fracture. None of the subjects sustained a mandibular fracture that required repeat operation where new fixation was required. We did not systematically include a pain scale for the patients postoperatively, nor a diary on how soon subjects were able to tolerate solid food without discomfort. Future studies involving these types of questionnaires can further discern the functional outcome improvement with optimal fracture and fixation patterns.

There are three important limitations to the interpretation of our results. First, there is a significant gender discrepancy, though not unusual since more male patients undergo MMA. Second, since only subjects with postoperative CT reconstruction were included, there were 36 other subjects who were not included. Finally, we do not have objective measures of function that allow correlation of fracture and fixation patterns to quality of life measures. This will be a fruitful area of investigation for increasing value-based outcomes of MMA surgery, where surgical success rate in the treatment of OSA and rapid return to function are equally important.

Conclusion

For OSA patients undergoing MMA, age and severity of disease do not contribute significantly to mandibular split patterns. To maximize area of passive bony overlap and thickness of buccal and lingual plates for rigid fixation, the most important factors are related to surgical technique. Anterior osteotomy just to the midline of the inferior border and horizontal osteotomy to the mandibular foramen are associated with optimal splits for large advancements.

Acknowledgments The authors would like to thank Dr. Pin-Yuan Chen of Peace Dental Clinic of Kaohsiung, Taiwan, who created the artwork in Figs. 1 and 2.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

References

1. Holty JE, Guilleminault C (2010) Maxillomandibular advancement for the treatment of obstructive sleep apnea: a systematic review and meta-analysis. Sleep Med Rev 14(5):287–297
2. Zaghi S, Holty JEC, Certal V, Abdullatif J, Guilleminault C, Powell NB, Riley RW, Camacho M (2016) Maxillomandibular advancement for treatment of obstructive sleep apnea: a meta-analysis. JAMA Otolaryngol Head Neck Surg 142(1):58–66
3. Liu SY et al (2016) Efficacy of maxillomandibular advancement examined with drug-induced sleep endoscopy and computational fluid dynamics airflow modeling. Otolaryngol Head Neck Surg 154(1):189–195
4. Liu SY et al (2015) Lateral pharyngeal wall tension after maxillomandibular advancement for obstructive sleep apnea is a marker for surgical success: observations from drug-induced sleep endoscopy. J Oral Maxillofac Surg 73(8): 1575–1582
5. Ljungqvist O, Scott M, Fearon KC (2017) Enhanced recovery after surgery: a review. JAMA Surg 152(3):292–298
6. Weeks WB, Schoellkopf WJ, Sorensen LS, Masica AL, Nesse RE, Weinstein JN (2017) The high value healthcare collaborative: observational analyses of care episodes for hip and knee arthroplasty surgery. J Arthroplast 32(3):702–708
7. Arnardottir ES, Mackiewicz M, Gislason T, Teff KL, Pack AI (2009) Molecular signatures of obstructive sleep apnea in adults: a review and perspective. Sleep 32(4):447–470
8. Verweij JP, Mensink G, Houppermans PNWJ, van Merkesteyn JPR (2015) Angled osteotomy design aimed to influence the lingual fracture line in bilateral sagittal split osteotomy: a human cadaveric study. J Oral Maxillofac Surg 73(10):1983–1993
9. Hamada S, Ikezoe K, Hirai T, Oguma T, Tanizawa K, Inouchi M, Handa T, Oga T, Mishima M, Chin K (2016) Evaluation of bone mineral density by computed tomography in patients with obstructive sleep apnea. J Clin Sleep Med 12(1):25–34
10. Arnett TR, Gibbons DC, Utting JC, Orriss IR, Hoebertz A, Rosendaal M, Meghji S (2003) Hypoxia is a major stimulator of osteoclast formation and bone resorption. J Cell Physiol 196(1):2–8
11. Kriwalsky MS, Maurer P, Veras RB, Eckert AW, Schubert J (2008) Risk factors for a bad split during sagittal split osteotomy. Br J Oral Maxillofac Surg 46(3):177–179
12. Camacho M, Liu SY, Certal V, Capasso R, Powell NB, Riley RW (2015) Large maxillomandibular advancements for obstructive sleep apnea: an operative technique evolved over 30 years. J Craniomaxillofac Surg 43(7):1113–1118
13. Plooij JM, Naphausen MTP, Maal TJJ, Xi T, Rangel FA, Swennnen G, de Koning M, Borstlap WA, Bergé SJ (2009) 3D evaluation of the lingual fracture line after a bilateral sagittal split osteotomy of the mandible. Int J Oral Maxillofac Surg 38(12):1244–1249

14. Wolford LM, Bennett MA, Rafferty CG (1987) Modification of the mandibular ramus sagittal split osteotomy. Oral Surg Oral Med Oral Pathol 64(2):146–155
15. Aarabi M, Tabrizi R, Hekmat M, Shahidi S, Puzesh A (2014) Relationship between mandibular anatomy and the occurrence of a bad split upon sagittal split osteotomy. J Oral Maxillofac Surg 72(12):2508–2513