Available online at www.sciencedirect.com
ScienceDirect
British Journal of Oral and Maxillofacial Surgery 61 (2023) 373–379
BRITISH Journal of Oral and Maxillofacial Surgery
www.bjoms.com

Impact of 3-dimensional anatomical changes secondary to orthognathic surgery on voice resonance and articulatory function: a prospective study

A. Valls-Ontañón [a,b,*], M. Ferreiro [c], B. Moragues-Aguiló [d], G. Molins-Ballabriga [d], S. Julián-González [d], A. Sauca-Balart [e], F. Hernández-Alfaro [a,b]

[a] Institute of Maxillofacial Surgery, Teknon Medical Center Barcelona, Barcelona, Spain
[b] Department of Oral and Maxillofacial Surgery, Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona, Spain
[c] Speech Therapy Department, Unimed-Rio Hospital, Rio de Janeiro, Brazil
[d] Anestalia, Teknon Medical Center Barcelona, Barcelona, Spain
[e] Speech Therapy Department, Universitat Autònoma de Barcelona, Bellaterra, Barcelona, Spain

Accepted 20 April 2023
Available online 26 April 2023

Abstract

An evaluation was made of the impact of orthognathic surgery (OS) on speech, addressing in particular the effects of skeletal and airway changes on voice resonance characteristics and articulatory function. A prospective study was carried out involving 29 consecutive patients subjected to OS. Preoperative, and short and long-term postoperative evaluations were made of anatomical changes (skeletal and airway measurements), speech evolution (assessed objectively by acoustic analysis: fundamental frequency, local jitter, local shimmer of each vowel, and formants F1 and F2 of vowel /a/), and articulatory function (use of compensatory musculature, point of articulation, and speech intelligibility). These were also assessed subjectively by means of a visual analogue scale. Articulatory function after OS showed immediate improvement and had further progressed at one year of follow up. This improvement significantly correlated with the anatomical changes, and was also notably perceived by the patient. On the other hand, although a slight modification in vocal resonance was reported and seen to correlate with anatomical changes of the tongue, hyoid bone, and airway, it was not subjectively perceived by the patients. In conclusion, the results demonstrated that OS had beneficial effects on articulatory function and imperceptible subjective changes in a patient's voice. Patients subjected to OS, apart from benefitting from improved articulatory function, should not be afraid that they will not recognise their voice after treatment.

Keywords: Bilateral sagittal split osteotomy; Le Fort osteotomy; Maxillary osteotomy; Misarticulation; Orthognathic surgery; Speech; Voice

Introduction

Orthognathic surgery (OS) combined with orthodontic treatment aims to re-establish harmony of the maxillomandibular complex and improve occlusion and temporomandibular joint function, enlarge the upper airway, and enhance facial aesthetics. However, it also has an impact on a patient's speech and voice.

* Corresponding author at: Maxillofacial Institute, Teknon Medical Center, Carrer de Vilana, 12 (desp. 185), 08022 Barcelona, Spain
E-mail address: avalls@institutomaxilofacial.com (A. Valls-Ontañón).

With regard to the structural modifications, OS and orthodontics have been shown in the literature to cause 3-dimensional anatomical changes in the dentoskeletal framework, and in the hyoid bone, larynx, and upper airway, amongst others,[1] which consequently imply adjustments in the positioning of the tongue and soft palate, and in overall oral and perioral muscle function.[2,3] These structures move together and in harmony to produce speech, so surgical changes to the maxillofacial complex may have an impact on a patient's voice.[4–6]

In brief, the lungs and thorax are the driving force, while the vocal tract is made up of the following passages or res-

https://doi.org/10.1016/j.bjoms.2023.04.007
0266-4356/

onators: the oral and nasal cavities, pharynx, and larynx. Within these cavities we find the articulators, which can be classed as active (tongue, mandible, soft palate (velum and uvula), and lips) or passive (teeth, alveolar ridge, hard palate, and maxilla). While the basic voiced sound is produced by vocal fold vibration, it is then modified by vocal tract resonators which produce a person's recognisable voice. The articulators also modify the voiced sounds to produce recognisable words. Thus, depending on the length of the tract and the different cross-sectional diameters along its length, the vocal tract acts as an acoustic modulating agent for the sound produced in the larynx, personalising the individual's voice. Moreover, through the modification and different positions adopted by the articulatory organs, the vocal tract has various shapes or configurations that also act as acoustic filters in word production.

We know of a few studies that have related specific malocclusions to misarticulation and voice quality, but the associations between them, together with abnormalities of tooth and jaw position and their correction in terms of OS and orthodontics, remain unclear.[5–10]

The aim of this study therefore was to evaluate the impact of OS on speech, addressing in particular the effects of skeletal and airway changes on the resonance characteristics of the voice and on articulatory function.

Material and methods

Study design and sample selection

A prospective, single-centre study was carried out by a multidisciplinary team of oral and maxillofacial surgeons, speech-language therapists, bioengineers, and nurses. A total of 29 consecutive patients who were diagnosed with dentofacial deformities and subjected to OS by the same surgeon (FHA) from January to June 2019 were included. The patients underwent anatomical and speech evaluations preoperatively and at short-term and long-term follow up (1 and 12 months, respectively) after surgery.

Patients selected were over 18 years of age with completed growth of the maxillofacial complex and a dentofacial deformity in need of jaw correction, they were native Spanish speakers with a hearing level of 25 dB or more in at least one ear as determined by audiometric testing at the octave frequencies of 250 - 8000 Hz, and had given written informed consent to participate in the study. Patients presenting with any craniofacial syndrome or disease that could compromise vocal fold or tract functionality were excluded, as were patients failing to attend the follow-up visits.

The study was approved by the Ethics Committee of Teknon Medical Centre (Barcelona, Spain) (ref VoiceStudy), and was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Department standard workflow protocol for OS

All patients followed the standard workflow for diagnosis, OS planning, and surgical splint fabrication in our department, as described elsewhere.[11,12] Minimally invasive orthognathic surgery[13] was performed under general anaesthesia.

Data acquisition and evaluation

Demographic data regarding age, sex, dental class according to angle classification, type of OS, and 3-dimensional skeletal movement, were compiled.

Radiographic and clinical evaluations were done at three time points: preoperatively after orthodontic treatment (T_0) and postoperatively at one month (T_1) and 12 months of follow up (T_2). Two postoperative time points were chosen to evaluate the short-term and long-term stability of the changes in anatomy and speech.

Anatomical variations in the vocal tract were analysed radiographically. Cone-beam computed tomography (CBCT) scans were collected in DICOM (Dental Imaging Communication) format using third-party software (Dolphin Imaging, version 11.95 Premium). The three CBCT datasets were superimposed in accordance with the voxel-based superimposition protocol[14] to assess longitudinal measurements of the maxillomandibular complex and articulators, and volumetric changes in the airway (Table 1 and Fig.1).[15] Two calibrated examiners (AVO and SPD), with

Table 1
Tomographic longitudinal and volumetric measurements.

Measurements		
Longitudinal		
Oral cavity	Height 1: posterior nasal spine (PNS) - base of tongue	
	Height 2: uvula - base of tongue	
	Sagittal 1: upper incisor – uvula	
	Sagittal 2: uvula - perpendicular posterior pharyngeal wall 1	
	Transversal 1: right greater palatine foramen - left greater palatine foramen	
	Transversal 2: right first molar palatal cusp - left first molar palatal cusp	
Hyoid bone	Height 1: sella- hyoid bone	
	Sagittal 1: perpendicular posterior pharyngeal wall 2 - hyoid bone	
	Sagittal 2: hyoid bone –B point	
Volumetric		
Nasopharynx	Oropharynx	Hypopharynx

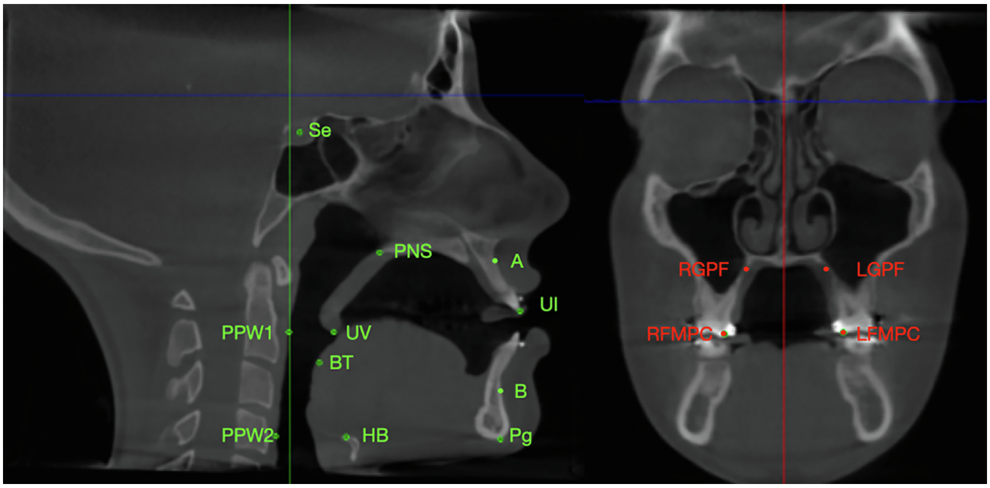
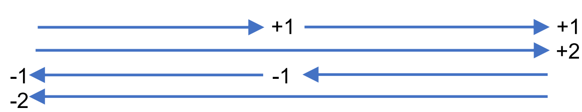


Fig. 1. Tomographic landmarks (Se: sella; PNS: posterior nasal spine; UI: upper incisor; UV: uvula; PPW1: perpendicular posterior pharyngeal wall 1; BT: base of tongue; B: B point; HB: hyoid bone; PPW2: perpendicular posterior pharyngeal wall 2; RGPF: right greater palatine foramen; LGPF: left greater palatine foramen; RFMPC: right first molar palatal cusp; LFMPC: left first molar palatal cusp.

Table 2
Articulatory function assessment. Compensatory musculature, point of articulation, and speech intelligibility scores depended on whether the functionality improved or worsened.

Functionality	Good	Medium	Bad
Compensatory musculature	No gestures	Soft gestures	Exaggerated gestures
Point of articulation	Phono articulatory structures in place	Most phono articulatory structures in place	Most phono articulatory structures in wrong place
Speech intelligibility	Sound is perceived without distortion	Perceived sound is similar to the expected one	Perceived and expected sounds are different
Score			

expertise in 3-dimensional superimposition techniques, tagged all the virtual models independently on two separate occasions spaced two weeks apart, thereby avoiding interobserver and intraobserver differences, respectively.

Speech assessment included both voice resonance and articulatory function. For these respective purposes, the patient's voice was recorded and his/her orofacial movements video recorded while reading aloud a list of words and sounds (Supplementary Material 1). This procedure was conducted in a quiet room, and the room's ambience was reduced thanks to a reflection filter (LD-RF1 - LD Systems). Speech samples were recorded through a microphone on a portable recorder (Zoom H4n Digital Recorder, Zoom Corp) that was maintained at a mouth-to-microphone distance of 30 cm. Changes in articulatory function were assessed by rating the following three items: use of compensatory musculature, point of articulation, and speech intelligibility (-2 = much worse; -1 = a little worse; 0 = no functional changes; +1 = a little improvement; and + 2 = much improvement) (Table 2).

Voice samples were relayed to the computer and acoustic analysis was performed using the middle three-second part with the MATLAB and Statistics Toolbox release 2019 software (The MathWorks Inc). The following voice parameters were evaluated at the three time points (T_0, T_1, and T_2) for each vowel: fundamental frequency (F0) or pitch (Hz), local jitter (%), and local shimmer (%). Formants F1 and F2 of vowel /a/ were obtained after applying the discrete Fourier transform (Table 3 and Fig. 2).

Finally, patients subjectively rated changes in the voice and articulation using a visual analogue scale (VAS) from 0 (no perceived change) to 10 (greatest perceived change).

Statistical analysis

A descriptive analysis was made of the demographic, anatomical, and voice study variables. The Shapiro-Wilk test was used to verify the adjustment to normal distribution of the different linear and volumetric dimensions.

Inferential analysis included the following statistical methods: a) analysis of variance (ANOVA) general linear model of repeated measures to compare evolution of the anatomical and volumetric parameters of the pathway and frequency of the formants over follow up, with the Bonferroni correction to assess short-term effects (T_1-T_0), stability (T_2-T_1), and long-term effects (T_2-T_0); b) binomial testing to contrast the equality of proportions of improvement and no improvement of articulatory function, and the chi-squared homogeneity test and Fisher's exact test to assess whether the evolution of articulatory function depended on the skeletal class of the individual; c) Spearman's non-linear correlation coefficient to estimate the degree of association between changes in anatomy (volumetric) and formant frequency; and d) the non-parametric Mann-Whitney U-test to study the relation between anatomical (volumetric) changes and evolution of articulatory function. The level of statistical significance was set at 5%.

Table 3
Description of voice parameters for each vowel (/a/, /e/, /i/, /o/, /u/).

	Description
Fundamental frequency (F0, pitch)	Number of vibrations produced by the vocal folds/second
Jitter	Disturbance of the fundamental frequency of the voice cycle to cycle (between the pulses of the voice)
Shimmer	Disturbance of the amplitude of the voice cycle by cycle (between the pulses of the voice)
Formant (/a/ vowel)	Frequency after vocal tract transfer function + resonance areas F1 and F2 are associated with tongue's height and anterior/posterior positions, respectively

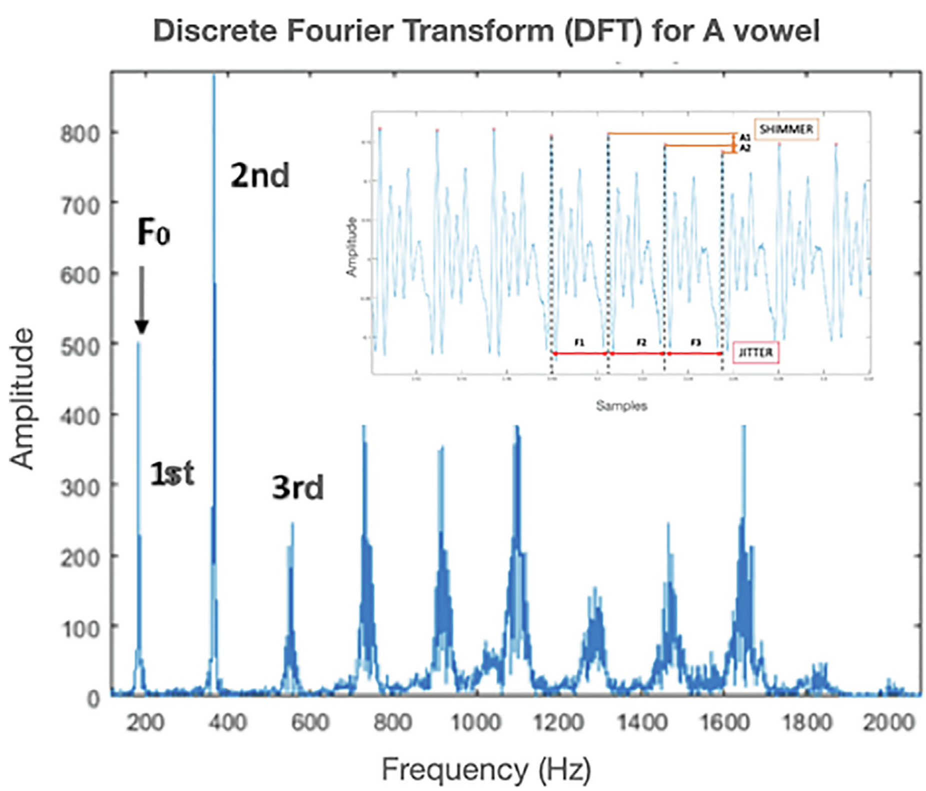


Fig. 2. Graphic description of voice resonance characteristics. The basic voiced sound is produced by vocal fold vibration (the fundamental frequency (F0) or pitch (Hz) is the number of vibrations produced by the vocal folds/second). Depending on the length of the tract and the different cross-sectional diameters along this length, the vocal tract acts as an acoustic modulating agent for the sound produced in the larynx, personalising the individual's voice. Through the modification and different positions adopted by the articulatory organs, the vocal tract has various shapes or configurations that also act as different acoustic filters in word production. These vocal tract transfer function and resonance areas are evaluated by the formants. For example, F1 and F2 of vowel /a/ are associated with the height and anterior/posterior position, respectively, of the tongue.

Results

In total 29 patients were included in the study. Twenty-one were female and eight male, with a mean (SD) age of 30.8 (8.8) years (range 20–52). Preoperatively, 16 patients presented with an underlying class II dentofacial deformity, 12 with a class III deformity, and one with a class I deformity. Overall, 3-dimensional widening of the maxillomandibular complex was obtained regardless of the initial dental class (specific 3-dimensional movements are summarised in Supplementary Material 2). No patients had undergone speech therapy before OS.

The outcomes that refer to evolution of the anatomical parameters are reported in Supplementary Material 3. The most relevant were a decreased posterior nasal spine (PNS) to base of tongue distance ($p<0.001$), an increased uvula to posterior pharyngeal wall distance ($p<0.001$), and an augmented hyoid bone height ($p<0.001$). Specifically, all the parameters were influenced significantly according to dental class (p=0.021, p=0.002, and p=0.045, respectively) (Supplementary Material 4).

Total airway volume expanded significantly ($p<0.001$), as did the three subregions (nasopharynx, oropharynx, and hypopharynx), the results being more relevant in class II than in class III patients (p=0.002).

Overall articulatory function improved significantly for all evaluated items: use of compensatory musculature, point of articulation, and speech intelligibility (Supplementary Material 5), with further improvement recorded in all class III patients. Specifically, improvement was the most common evolution for the phonemes /PA/ (p=0.035), /SA/ (p=0.011), and /FA/ (p=0.035). However, for /KA/, an absence of changes predominated (p=0.003). Statistical analysis to correlate changes in anatomy and articulatory function revealed a significant influence of uvula to posterior pharyngeal wall distance on enhanced articulation of /LA/ at T_1 (p=0.001) and T_2 (p=0.001); PNS to base of tongue distance on /RA/ at T_2 (p=0.048); upper incisor to uvula distance on /SA/ at T_2 (p=0.035) and on /LA/ at T_2 (p=0.001); and hyoid bone to B point distance on /LA/ at T_2 (p=0.043). Similarly, significant correlations were found between /LA/ and nasopharynx (p=0.009), oropharynx (p=0.002), and total airway volume enlargement at T_2 (p=0.002).

Regarding acoustic analysis, no substantial changes in F0 were recorded over time (Supplementary Material 6). However, some correlations were related to airway volume: a) the greater the immediate gain in volume of the nasopharynx (T_1-T_0), the lower the increase in the pitch of vowel /u/ (indirect relation with moderate correlation, r = -0.46; p=0.027); and b) the greater the final increase in the hypopharynx (T_2-T_0), the greater the increase in pitch. This was significant for vowels /a/, /i/, and /o/ (direct relation with r = 0.48 (p=0.022), r = 0.42 (p=0.048), and r = 0.44 (p=0.034), respectively) and there was a non-significant trend for vowels /e/ and /u/ (direct relation with r = 0.34 (p=0.114), and r = 0.40 (p=0.061), respectively).

No significant differences were found in the frequency of vowel /a/ emission over time, for both F1 and F2 (Supplementary Material 7). However, some significant correlations were found between a variation in the frequency of F2 and the following anatomical structures: a) a moderate and inverse correlation (r = -0.46) with the distance between the uvula and posterior pharyngeal wall at T_2 (p=0.02); b) a direct correlation (r=0.62) with variations in hypopharyngeal volume at T_1 (p = 0.001); and c) a direct correlation (r = 0.40) with variations in nasopharyngeal volume at T_2 (p = 0.046) (Supplementary Material 8).

Jitter evaluation presented significant changes over time for vowel /i/ (p = 0.023, Friedman), while the other vowels remained stable (Fig. 3). A few anatomical correlations were detected: a) the more the distance from the hyoid bone to sella decreased over the short term (T_1-T_0), the greater the reduction in local jitter of vowel /u/ (direct correlation with r = 0.54 (p = 0.008)); and b) the more the sagittal distance of the hyoid bone to point B decreased (T_2-T_0), the greater the reduction in local jitter of vowel /u/ (direct correlation with r = 0.49 (p = 0.017)).

Shimmer decreased over time, but with no statistically significant differences (Supplementary Material 9). The following anatomical correlations were observed: a) the greater the reduction in distance from the hyoid bone to sella over the short term (T_1-T_0), the greater the reduction in local shimmer of vowel /u/ (direct correlation, r=0.50 (p=0.015); b) the more the stability of the volume of the oropharynx was maintained, the more the shimmer of vowels /a/ and /e/ decreased (direct correlation with r = 0.44 (p = 0.036) and r = 0.41 (p = 0.049), respectively); and c) the greater the expansion of the hypopharynx, the greater the reduction in shimmer of vowel /o/ (indirect correlation with r = -0.43 (p = 0.043)).

Finally, the patient-reported subjective VAS score was 0 for perceived voice modification and 7 for change in articulatory function.

Discussion

The results of this before-after study revealed an immediate improvement in articulatory function after OS that further progressed over one year of follow up. This improvement

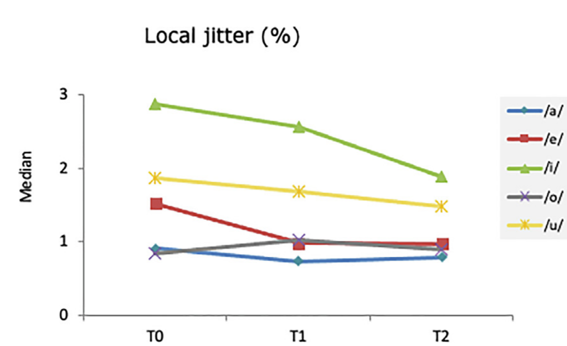


Fig. 3. Evolution over time of the jitter (%) of each vowel. Jitter is the disturbance of the fundamental frequency (F0) of the voice cycle to cycle (between the pulses of the voice).

significantly correlated with the anatomical changes, and notably was also perceived by the patient. On the other hand, although a slight modification in resonance was recorded, it was not subjectively perceived by the patients.

Although the correction of a malocclusions may possibly result in the improvement of speech discrepancies, clear supporting evidence in the literature is lacking due to the heterogeneity of study samples regarding the diagnosed malocclusion, type of OS performed, patient's language, incorporation of individuals receiving adjunctive speech therapy, and differences in the methodology used for speech assessment.[16,17] In this context, although there was important inter-subject variability regarding the initial diagnosis in the present study, the UI-STP (upper incisor to soft tissue plane) protocol,[12] which usually implies broadening of the maxillomandibular complex (Supplementary Material 2), made the sample more homogeneous.

As reported, these surgical modifications induce enlargement of the upper airway. They pull the hyoid bone upwards and forwards, and displace the uvula or soft palate forwards,[1] thus producing the same variations in the vocal tract and its resonators as those that have been related in the literature to adjustments in voice parameters.[6,7,9,18] Our outcomes showed that F0 increased immediately after surgery, but decreased and returned to preoperative levels after one year. Similar to the observations of Niemi et al[7] these changes were not statistically significant. This evolution over time can be attributed to postoperative changes in the position of the hyoid bone, which tends to return to its original position during the postoperative period, and is closely connected to the larynx.[6] Voice F0 is determined by the number of cycles produced by the vocal folds/second (Table 3), and basically depends on vocal fold length, mass, and tension during speech.[7,18,19] Our study found evidence of a relation between F0 changes and enlargement of the hypopharynx, meaning that the hyoid bone, and consequently the larynx, adopts a more anterosuperior position and the vocal cords increase in length.

On the other hand, our results showed significant correlations between the variation in the frequency of F2 of vowel /a/ and the anatomical changes. This was to be expected since F2 is directly related to the anteroposterior position of the tongue, and all patients received maxillary or mandibular advancement. In the same context, there is an inverse relation between F1 and the high or low position of the tongue, though our results revealed no significant correlations. Although skeletal forward movement also improves tongue position and reduces the height of the base of the tongue, it was not enough to reach statistical significance. Subjectively in the general population, the reported acoustic changes are imperceptible,[7] though they could become evident in specialised singers.

Jitter and shimmer analyse the perturbation of F0 and waveform amplitude, respectively. The reported outcomes showed a reduction in both parameters and meant that voice disturbance or cycle-to-cycle variations decreased after surgery. This also significantly correlated with a more anterosuperior position of the hyoid bone and therefore of the larynx, with consequent stretching of the vocal cords.

OS combined with orthodontics corrects occlusion, thus affording a proper relation between the main articulators (lips, teeth, alveolar ridge, maxilla, mandible, soft palate, and tongue), and appropriate functioning of the perioral muscles, which is related to improved articulatory function. Moreover, 3-dimensional augmentation of the oral cavity results in a better tongue posture, which further improves airway volume and function of the tongue as an articulator. Class II patients are characterised by an inadequate tongue posture with a high back zone due to the lack of jaw space, and a parted-lips posture with superior hypotonicity and lower hypertonicity. Patients with class III malocclusion generally exhibit a parted-lips posture or sealing with pressure, hypotonic jaw elevator muscles, a recessed tongue position on the floor of the mouth, tongue thrust swallowing, forward displacement of the tongue during speech, and chewing performed predominantly with vertical movements.

Our results reporting overall improvement of articulatory function are in line with those found in the literature.[17,19–21] Moreover, these changes are evident to patients. We wish to emphasise that, to our knowledge, this is the first paper to analyse articulatory function in terms of the compensatory musculature, apart from point of articulation and speech intelligibility.

However, the present study lacks the assessment of phonemes involving velopharyngeal function, since endoscopic recordings could not be performed in the clinic. Instead, we focused on phonemes involving anterior anatomical structures that could be evaluated directly and recorded with a camera. For the same reason, cleft patients were excluded from the study.[17,22–24] Another limitation is that the first evaluation was done at the end of the first stage of orthodontic treatment when the teeth had been decompensated. Since this usually worsens speech, it would have been better if it had been done before orthodontic treatment started.

Although OS affords beneficial effects, it does not mean that speech therapist intervention is not required.[20] While some initial conditions, such as open bite with atypical swallowing require preoperative logopedical management,[25] some patients can benefit from postoperative therapy for speech improvement as well as smile recovery.[26,27]

We can conclude that patients subjected to OS benefit from improved articulatory function, and they should not be afraid that they will not recognise their voice after treatment.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patient permission

Ethics Committee of Teknon Medical Centre (Barcelona, Spain) (Ref. VoiceStudy). Patients' permission obtained.

Acknowledgements

The authors thank all the staff members at the Institute of Maxillofacial Surgery, Teknon Medical Centre (Barcelona), for their administrative and clinical support. Thanks are also due to Silvia Perez Diz, Fernanda Castellanos, Stella Papamichail, and Sabina Kurbegovic.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bjoms.2023.04.007.

References

1. Giralt-Hernando M, Valls-Ontañón A, Haas Junior OL, et al. What are the surgical movements in orthognathic surgery that most affect the upper airways? A three-dimensional analysis. *J Oral Maxillofac Surg* 2021;**79**:450–462.
2. Glass L, Knapp J, Bloomer HH. Speech and lingual behavior before and after mandibular osteotomy. *J Oral Surg* 1977;**35**:104–109.
3. Souza Pinto GN, Iwaki Filho L, Previdelli IT, et al. Three-dimensional alterations in pharyngeal airspace, soft palate, and hyoid bone of class II and class III patients submitted to bimaxillary orthognathic surgery: a retrospective study. *J Craniomaxillofac Surg* 2019;**47**:883–894.
4. Wakumoto M, Isaacson KG, Friel S, et al. Preliminary study of articulatory reorganisation of fricative consonants following osteotomy. *Folia Phoniatr Logop* 1996;**48**:275–289.
5. Ruscello DM, Tekieli ME, Van Sickels JE. Speech production before and after orthognathic surgery: a review. *Oral Surg Oral Med Oral Pathol* 1985;**59**:10–14.
6. Jorge TM, Brasolotto AG, Gonçales ES, et al. Influence of orthognathic surgery on voice fundamental frequency. *J Craniofac Surg* 2009;**20**:161–164.
7. Niemi M, Laaksonen JP, Peltomäki T, et al. Acoustic comparison of vowel sounds produced before and after orthognathic surgery for mandibular advancement. *J Oral Maxillofac Surg* 2006;**64**:910–996.
8. Lee AS, Whitehill TL, Ciocca V, et al. Acoustic and perceptual analysis of the sibilant sound /s/ before and after orthognathic surgery. *J Oral Maxillofac Surg* 2002;**60**:364–373.
9. Tatli U, Surmelioglu O, Tukel HC, et al. Effects of orthognathic surgery on voice characteristics. *J Oral Maxillofac Surg* 2021;**79**(225):e1–e15.
10. Emrani E, Ghaemi H, Labafchi A, et al. The effect of bimaxillary orthognathic surgery on voice characteristics in skeletal class 3 deformity patients: an evaluation using acoustic analysis. *J Craniofac Surg* 2021;**32**:2129–2133.
11. Hernández-Alfaro F, Guijarro-Martínez R. New protocol for three-dimensional surgical planning and CAD/CAM splint generation in orthognathic surgery: an in vitro and in vivo study. *Int J Oral Maxillofac Surg* 2013;**42**:1547–1556.
12. Hernandez-Alfaro F. Upper incisor to soft tissue plane (UI-STP): a new reference for diagnosis and planning in dentofacial deformities. *Med Oral Patol Oral Cir Bucal* 2010;**15**:e779–e781.
13. Hernández-Alfaro F, Guijarro-Martínez R. "Twist technique" for pterygomaxillary dysjunction in minimally invasive Le Fort I osteotomy. *J Oral Maxillofac Surg* 2013;**71**:389–392.
14. Haas Junior OL, Guijarro-Martínez R, Sousa Gil AP, et al. Cranial base superimposition of cone-beam computed tomography images: a voxel-based protocol validation. *J Craniofac Surg* 2019;**30**:1809–1814.
15. Guijarro-Martínez R, Swennen GR. Three-dimensional cone beam computed tomography definition of the anatomical subregions of the upper airway: a validation study. *Int J Oral Maxillofac Surg* 2013;**42**:1140–1149.
16. Hassan T, Naini FB, Gill DS. The effects of orthognathic surgery on speech: a review. *J Oral Maxillofac Surg* 2007;**65**:2536–2543.
17. Chanchareonsook N, Samman N, Whitehill TL. The effect of cranio-maxillofacial osteotomies and distraction osteogenesis on speech and velopharyngeal status: a critical review. *Cleft Palate Craniofac J* 2006;**43**:477–487.
18. Mishima K, Moritani N, Nakano H, et al. Voice characteristics before versus after mandibular setback surgery in patients with mandibular prognathism using nonlinear dynamics and conventional acoustic analyses. *J Craniomaxillofac Surg* 2013;**41**:706–709.
19. Van Lierde KM, Schepers S, Timmermans L, et al. The impact of mandibular advancement on articulation, resonance and voice characteristics in Flemish speaking adults: a pilot study. *Int J Oral Maxillofac Surg* 2006;**35**:137–144.
20. Ward EC, McAuliffe M, Holmes SK, et al. Impact of malocclusion and orthognathic reconstruction surgery on resonance and articulatory function: an examination of variability in five cases. *Br J Oral Maxillofac Surg* 2002;**40**:410–447.
21. Ghaemi H, Emrani E, Labafchi A, et al. The effect of bimaxillary orthognathic surgery on nasalance, articulation errors, and speech intelligibility in skeletal class III deformity patients. *World J Plast Surg* 2021;**10**:8–14.
22. Alaluusua S, Turunen L, Saarikko A, et al. The effects of Le Fort I osteotomy on velopharyngeal function in cleft patients. *J Craniomaxillofac Surg* 2019;**47**:239–244.
23. Chua HD, Whitehill TL, Samman N, et al. Maxillary distraction versus orthognathic surgery in cleft lip and palate patients: effects on speech and velopharyngeal function. *Int J Oral Maxillofac Surg* 2010;**39**:633–640.
24. Janulewicz J, Costello BJ, Buckley MJ, et al. The effects of Le Fort I osteotomies on velopharyngeal and speech functions in cleft patients. *J Oral Maxillofac Surg* 2004;**62**:308–314.
25. Foletti JM, Antonarakis GS, Galant C, et al. Is atypical swallowing associated with relapse in orthognathic patients? A retrospective study of 256 patients. *J Oral Maxillofac Surg* 2018;**76**:1084–1090.
26. Hong SO, Baek SH, Choi JY. Physical therapy for smile improvement after orthognathic surgery. *J Craniofac Surg* 2017;**28**:422–426.
27. Gallerano G, Ruoppolo G, Silvestri A. Myofunctional and speech rehabilitation after orthodontic-surgical treatment of dento-maxillofacial dysgnathia. *Prog Orthod* 2012;**13**:57–68.