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ORIGINAL ARTICLE

Variations in Function and Vocal Acoustic Characteristics After Orthognathic Surgery: Preliminary Results

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ABSTRACT

Objective: To determine the effects of orthognathic surgery on oral function and vocal quality in order to assess the need for speech therapy after surgery. **Material and Methods:** Thirty-seven patients scheduled for mono-jaw surgery, specifically maxillary (G1:15 patients), mandibular advancement (G2:10 patients) or mandibular set-back (G3:12 patients), were recruited for this prospective cohort study. Evaluation of oral functions, video recordings of speech articulation and audio recordings of voice were obtained before surgery (T0), and at 1 (T1) and 6 months (T2) after surgery. Spectrographic analysis and self-evaluation questionnaire regarding the vocal performance (VAPP) were performed. Both qualitative and quantitative statistical analysis was performed, mainly using generalized linear models for dichotomous data ($p<0.05$). **Results:** The formant frequencies (F1 and F2) of the main vowels vary after orthognathic surgery according to the type of surgery. Before surgery, 84% of patients analyzed showed difficulties in breathing and positioning the tongue both at rest and swallowing. Thanks to surgical correction of the malocclusion, the major part of these issues were resolved within 6 months. In 25% of cases, a change in the voice and/or articulation had occurred. **Conclusion:** Vocality improves after orthognathic surgery and it changes in relation to the type of surgery. However, vocality did not normalize completely. Speech assessment should be considered after surgery in order to offer adequate speech therapy if necessary.

Keywords: Orthodontics; Orthopedics; Pathology, Oral; Surgery, Oral; Oral Health.

Introduction

Speech and acoustic modification could alarm those patients that are treated orthodontically [1], especially when orthodontic appliances are positioned in the lingual part of the mouth [2-6]. Moreover, various studies have been carried out on the relationship between orthognathic surgery and language [7-14]. Changes in the length and/or relative position of the jaws, and differences in the degree of mouth opening and tongue position can affect both the articulation and vocal features of orthognathic surgery patients. Most of the research carried out to date shows that orthognathic surgery can eliminate [12] or drastically reduce errors in language articulation [11,14-17] although a minority of studies have not reached the same conclusion [9,17].

On the other hand, clear aligner therapy seems to less influence the speech [18,19]. Nevertheless, this discrepancy may be due to differences in the types of analysis performed and the different malocclusions investigated.

Vowels have been studied less frequently than consonants [20], as what appears to occur most frequently in patients with malocclusion is a distortion of the sibilants [21,22]. We do know that the most evident link between dysgnathia and dyslalia occurs in cases of open bite [23,24], but there are still considerable gaps in the research.

Hence the aim of this study was to contribute to the body of knowledge on the topic by assessing the effects of different types of orthognathic surgery on oral function and the production of language, with particular reference to the patients' vocal quality. The null hypothesis is that patients who underwent orthognathic surgery do not show an improvement in both language articulation and vocal features after orthognathic surgery. If the null hypothesis would have to be accepted, further speech therapy should be performed after the orthognathic surgery in order to improve the speech ability.

Material and Methods

Sample Selection and Ethical Clearance

Thirty-seven patients (21 females – 56.8% – and 16 males – 43.2%; mean age 24.9 ± 3.4 years [males = 29.5±2.9 / females = 21.6±4.1]) were scheduled for mono-jaw surgery. According to age, they were divided into: 17-25 years = 73.0%; 26-35 years = 11.0% and 36-51 years = 16.0%.

To be enrolled in this prospective study, subjects should have respected the subsequent inclusion criteria: A) Italian native language speakers; B) Absence of multiple malformation syndromes; C) Absence of cleft lip and cleft palate; D) Normal lingual frenulum; and E) Absence of sensory deficits

The study was carried out in accordance with the Helsinki declaration (64th WMA General Assembly, Fortaleza, Brazil, 2013) and the study design was approved by the ethical committee of the postgraduate School of Orthodontics of University of Ferrara, with protocol n°17/2016.

Collection of Data

After that informed consent was acquired, and video and voice recordings of each patient were collected in the same silent room. Voice recordings were collected using a Samsung notebook (mod. 300E5A-S0B), dedicated software (Wavesurfer version 8.5.8: http://www.speech.kth.sc/software/) and an external Trust microphone (mod.11917). The angulation of the microphone was maintained at 45°, but the recording distance varied from 3 to 10 cm. Video recordings were obtained using a Canon camera Power shot A3200IS, transferred onto the same notebook as AVI files and analyzed by means of Windows Media Player.

The material collected consisted of:

• The 5 vowels;

• Vocalization of the vowel /a/ emitted at constant intensity and pitch for at least 4 seconds, without any interruptions of sonority;

• A series of words of two and three syllables containing all the phonemes;

• VCV Nexus containing all the phonemes;

• The sentence: "The flowerbeds are pretty";

• An ad hoc description of an image.

Recordings were collected on the day before orthognathic surgery (T0), at 1 month (T1) and 6 months (T2) after orthognathic surgery. All data recorded were analyzed at a later date. Therefore, an observation form was filled out in collaboration with each subject investigated, concerning their oro-facial muscle functionality, oral and perioral sensitivity, the evolution of their chewing ability during the post-surgery period, and the presence/absence of speaking difficulties, before and after surgery. Regarding the sample, 5 patients, all affected by Class II skeletal malocclusion, dropped out after T1. Therefore, the remaining sample consisted of 32 patients.

Surgical Procedures

The patients who were included in the study were affected by either skeletal Class II (7 patients) or Class III malocclusion (25 patients). They were divided into 3 groups depending on the type of orthognathic surgery executed to solve the skeletal imbalance.

Specifically:

• 14 patients affected by skeletal Class III malocclusion (ANB≤-2°; Wits≤-3mm) underwent surgical maxillary advancement (G1), due to severe skeletal maxillary retrusion (SNA≤75°);

• 7 patients affected by skeletal Class II malocclusion (ANB≥6°; Wits≤+3mm) underwent surgical mandibular advancement (G2), due to skeletal mandibular retrusion (SNA≤73°);

• 11 patients affected by skeletal Class III malocclusion (ANB≤-2°; Wits≤-3mm) underwent surgical mandibular set back (G3), due to skeletal mandibular protrusion (SNB≥84°).

Maxillary advancement was carried out after osteotomy according to Le Fort I, while mandibular surgery was performed through bilateral sagittal osteotomy of the ramus (BSSO). Surgical procedures had been performed by the same oro-maxillo-facial surgeon (B.U.). No patients were scheduled for sectorial osteotomy.

Data Analysis

A spectrographic analysis of the main vowels /a/, /i/, /u/ exam was carried out by an expert speech pathologist (S.P.) using an SFS/-Esection 2.2 system (Mark HcKvale University College London 2007) and Wavesurfer 8.5.8 software for each subgroup analyzed.

A perceptive-semi-objective assessment of vocal quality (5 vowels, vocalization of /a/ and sentence "*the flowerbeds are pretty*") was performed by four professionals [two speech pathologists (M.N. S.P.), one speech therapist (G.G.) and one non-expert dentist (M.D.)], using modified GIRBAS method [25]. Specifically, the GIRBAS method was modified for the purposes of this prospective study. This is a semi-quantitative scale assigning 0 points to the standard voice, 1 point for a light defect, 2 points for a moderate defect and 3 points for a severe defect. The GIRBAS scale measures the following parameters; "G" = global grade (grade); "I" = unstable voice (instability); "R" = hoarse (roughness); "B" = blown (breathiness); "A" = asthenic (asthenicity) and "S" = pressed (strain); we also measured "d" = diplophonic; "t" = tremor; and "n" = nasality.

Patient's subjective evaluation of vocal distortion was performed through VAPP questionnaire (Voice Activity and Participation Profile) at T2 [26].

Clinical evaluation of tongue position at rest and during swallowing was performed by an expert speech pathologist (S.P.) and a speech therapist (G.G). The aim was to verify whether or not the position of the tongue had been corrected by the surgery at T1 and evaluate if, for each of the two tongue positions and for each vowel investigated (/a/, /i/, /u/), formant frequencies improve, remain stable, or decrease, without reference to formant type.

Clinical evaluation of oral, perioral and stereognosis sensitivity and muscle functionality was performed. Muscle functionality was measured through clinical observation of the patient in the act of performing the subsequent movements: 1) Protrusion, lateral displacement, and extension of the lips; 2) Protrusion, lateral displacement, elevation, and retraction of the tongue. Both symmetrical and asymmetrical swelling at both cheeks and upper and lower vestibules was evaluated. The perioral sensitivity was detected by touching lips, cheeks and forehead with a tongue depressor, indicating the presence of defensive reactions, hypersensitivity, and physiological or pathological reflex reactivity. In the same manner, also intra-oral sensitivity was detected by touching the appropriate anatomical sites such as tongue base, veil of the palate and palatine pillars, observing the elicitation of physiological reflexes.

The acoustic analysis of the voice had been analyzed keeping the three subgroups separated in order to distinguish what kind of surgery modified the formant frequencies (F1 and F2) of the main vowels /a/, /i/, /u/.

The remanent analysis had been analyzed on the whole sample, considering that all aimed to normalize the sagittal inter-jaw relationship.

The inclusion criteria are summed up according to the following PICOs criteria:

- Problems (P): subjects who need orthognathic surgery due to severe skeletal Class II and III malocclusion and facial esthetic imbalance.
- Intervention (I): maxillary advancement for G1, mandibular advancement for G2, and mandibular set-back for G3
- Control (C): results are not compared with a control group.
- Outcomes (O): acoustic analysis of the voice (spectrographic analysis), perceptive assessment of vocal quality (modified GIRBAS method), self-evaluation (VAPP questionary) and clinical examination (stereognosis, oro-facial sensory and muscle functionality).

Data were acquired at the following time points:

- T0: before orthognathic surgery;
- T1:1 month after orthognathic surgery;
- T6: 6 months after orthognathic surgery.

Statistical Analysis

Statistical analysis was performed on both a qualitative level, using descriptive indices and a quantitative level, mainly using generalized linear models for dichotomous data. Statistical significance was set at $p<0.05$.

Results

Acoustic Analysis of the Voice

Qualitative analysis was performed on the progression of the formant frequencies (F1 and F2) of three distinct vowel sounds (/a/, /i/ and /u/). Specifically, spectrographic analysis was carried out on data acquired at T0 and T1, but not at T2. As a matter of fact, vocal changes provoked by surgery should be measured immediately after the surgery, due to the fact they persist over time.

Results are graphically illustrated for each group analysed (Figure 1 to 3) and the general trends are summed up with positive or negative signs when the percentage of patients who showed an increase or a decrease of the formant frequency is higher than 50%, respectively. Results obtained in G1 are shown in Figure 1. Patients undergoing upper jaw advancement surgery mostly demonstrated an increase as regards the vowel /a/ (73% of cases) in F1. However, no evident changes are detected regarding F2. Regarding vocal /i/, both F1 and F2 decreased (54.5% and 66.7%, respectively) after surgery. In the vowel /u/, no difference has been detected for F1, whereas 61.5% of the sample has shown a decrease in F2.

G1 (Figure 1): - /a/: F1+
- /i/: F1-; F2-
- /u/: F2-

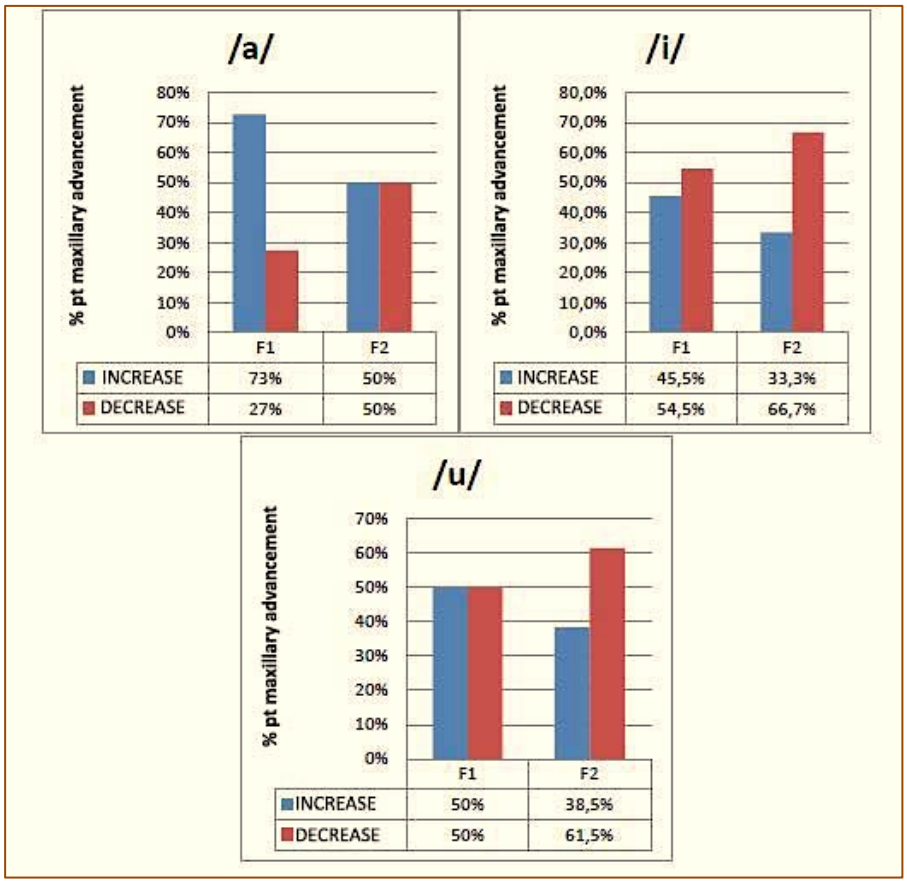

Figure 1. Spectrographic analysis of three distinct vowel sounds (/a/, /i/ and /u/) at T0 and T1 on the progression of the formant frequencies (F1 and F2) for the group G1.

Results obtained in G2 are shown in Figure 3. About the analysis of vowel /a/, patients showed generally an increase of F1 (80%) and a decrease of F2 (71.4%) after orthognathic surgery. Regarding vowel /i/, patients showed a decrease of F1 (66.7%), although an increase of F2 (83.3%) had been recorded in the major part of patients.

About the vowel /u/, the majority of patients showed an increase of F1 (85.7%), but a decrease of F2 to a lesser extent (57.1%).

G2 (Figure 2): - /a/: F1+; F2-
- /i/: F1-; F2+
- /u/: F1+; F2-

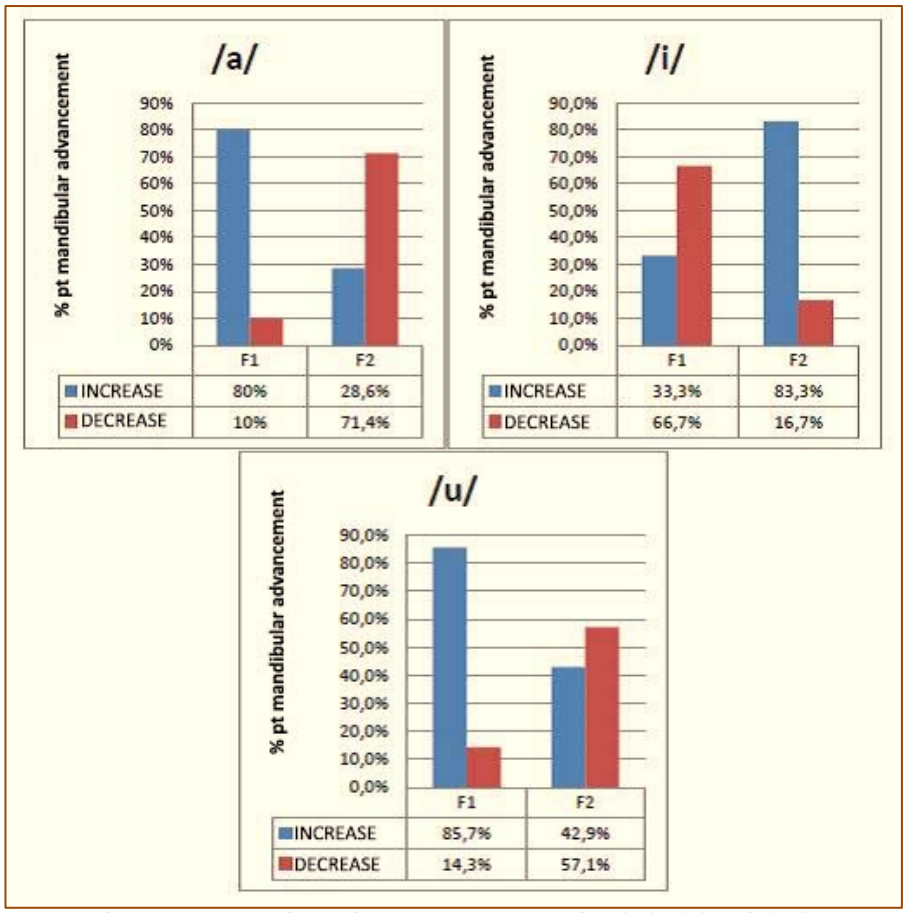

Figure 2. Spectrographic analysis of three distinct vowel sounds (/a/, /i/ and /u/) at T0 and T1 on the progression of the formant frequencies (F1 and F2) for the group G2.

Results recorded in G3 are graphically illustrated in Figure 3. For patients with mandibular set back, a strong increase of F1 was observed in the major part of patients (77.7%) when vowel /a/ was investigated, while only 54.6% of patients showed an increase of F2. Regarding the vowel /i/, differences detected are minimal after orthognathic surgery; as a matter of fact, there is an increase in 55.6% of F1 and a decrease in 60% of the sample of F2. For the vowel /u/, the major part showed an important decrease of F1 (75% of the population), whereas only 54.5% of the patients showed a decrease of F2.

G3 (Figure 3): - /a/: F1+; F2+
- /i/: F1+; F2-
- /u/: F1-; F2+

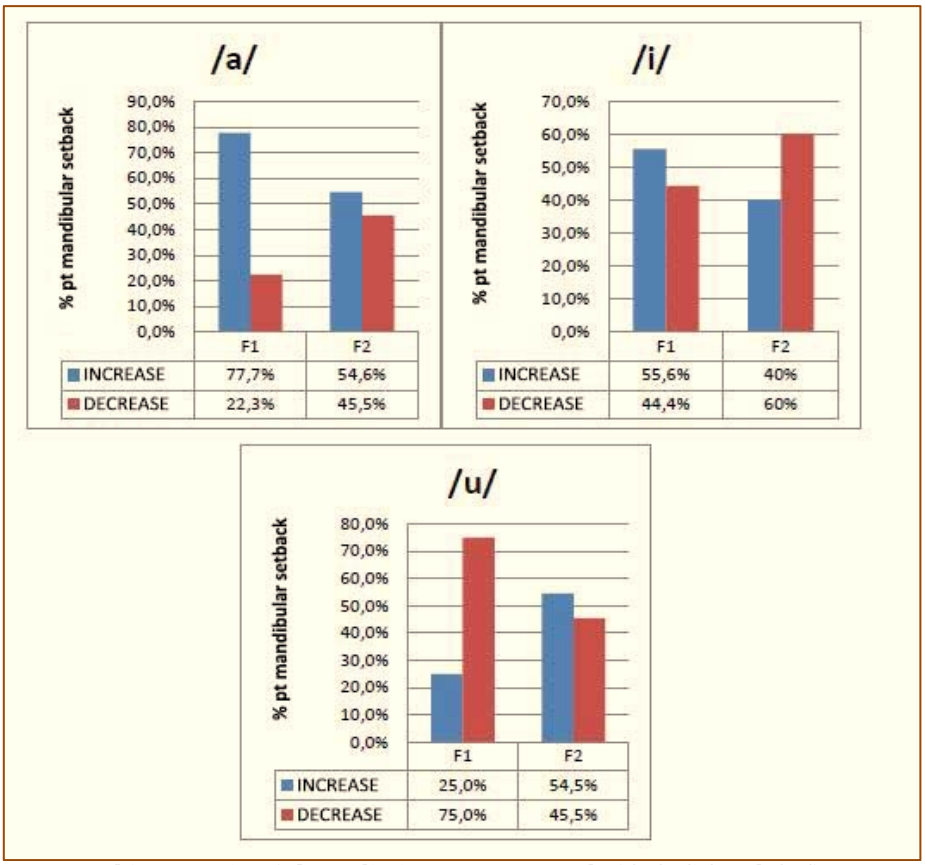

Figure 3. Spectrographic analysis of three distinct vowel sounds (/a/, /i/ and /u/) at T0 and T1 on the progression of the formant frequencies (F1 and F2) for the group G3.

Perceptive Assessment of Vocal Quality

In most cases (89%), patients demonstrated voice defects (G) at T0 due to the presence of anomalies at the level of one or more divisions of the GIRBAS scale. After surgery (T1), these defects were still present only in 50% of the whole sample, highlighting a general improvement, with a complete recovery at T2. Specifically, only defects in "A" and "d" have been resolved completely at T1, although the other parameters investigated showed an important decrease at T1. Considering all parameters investigated, they showed a complete remission at T2 (Figure 4).

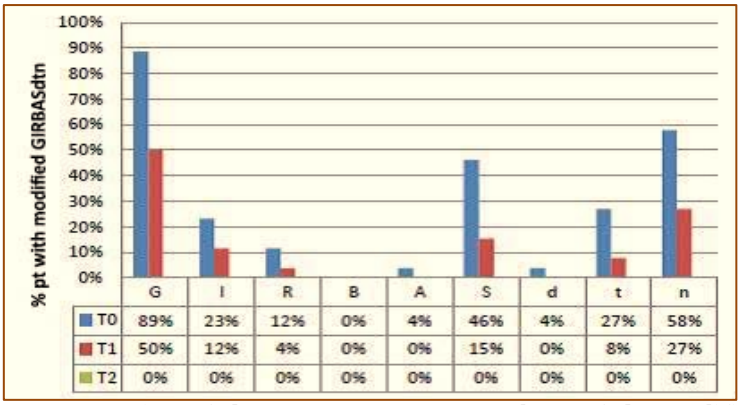

Figure 4. Graphical representation of the results at T0, T1 and T2 of the modified GIRBAS method specifically modified for the purposes of the study (GIRBASdtm). "G" = global grade (grade); "I" = unstable voice (instability); "R" = hoarse (roughness); "B" = blown (breathiness); "A" = asthenic (asthenicity) and "S" = pressed (strain); we also measured "d" = diplophonic; "t" = tremor; and "n" = nasality.

Self-Evaluation

After analysis of the VAPP questionary, due to the very small variability in responses, the scale was discretized using only two possible values to indicate the presence/absence of problems in a specific social area investigated. Results are shown in Figure 5.

At T1, 11 patients reported general vocal problems in (about 32% of the whole sample). Specifically, the patients most often (>20%) have indicated a problem in item n.6, namely: "*Do people ask you to repeat what you have just said because of your voice problem*?". However, we did note a discrepancy with these responses, as only 3 of the whole patients had responded positively to item n.1, i.e. "*How severe is your voice problem at the moment*?" Also for item n.12, namely "*Does your speech problems influence your communication in the noisy places*?", 3 patients reported a positive answer for the presence of this problem.

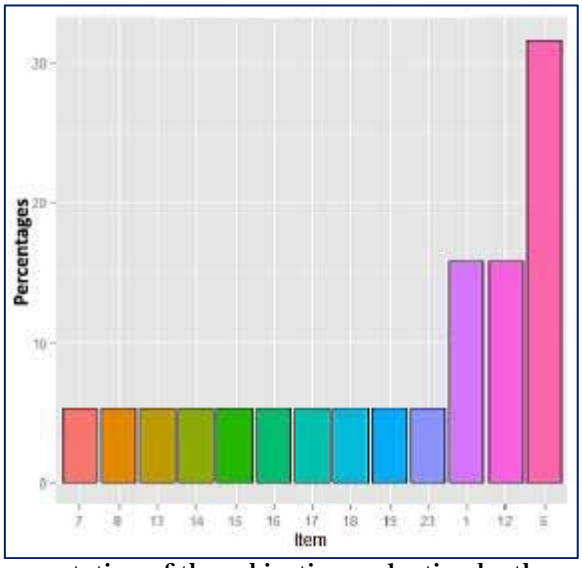

Figure 5. Graphical representation of the subjective evaluation by the patient filling in a VAPP questionnaire.

Clinical Examination

Tongue Position and Formant Variation

Data were analysed through an adapted version of a generalized linear model. Results about the percentage of conditions in which the tongue can be considered improved, stable or worsened after surgery (T1) are shown in Figure 6. After surgery, the number of patients in whom tongue position had improved at swallowing is quite similar with respect to those in whom it remained stable (45.4% vs 40.9%, β=0.10, z=1.78, p=0.08), while a very small minority (13.6%) of subjects evidenced a worsened tongue position (β=-0.58, z=-3.29, p<0.01). Only 4.5% of the whole sample registered a worsening of the tongue position at rest. This difference in percentage among patients who showed a worsening of tongue position at both rest and swallowing is statistically different (13.6% vs 4.5%, β =-0.20, z=-3.29, p<0.01).

Furthermore, results as regards formant frequencies variation in relation to tongue position at rest and at swallowing are shown in Table 1 and Figures 7 (at rest) and 8 (during swallowing). At rest evaluation, there is a poor relationship between formant frequencies variations and tongue position (improved or worsened), although an improved tongue position at rest is correlated with a decreased formant frequencies variation of the vowel /i/ and vice versa. A particular trend became clearer when evaluation of swallowing occurs. As a matter of fact, for all three vowels investigated, there is a correlation between improved tongue position and an increase

in the formant frequency variation, whereas a decreased formant frequency variation occurs when the tongue position worsened. This is particularly true for the vowel /a/. As a matter of fact, if the tongue position improves the formant frequency increases. Differently, when the tongue position gets worse the formant decreases (β =-0.38, z =-3.67, p<0.001).

Table 1. Difference between the stable formant and the other two (estimated parameters for generalized linear models).

Vowel	Tongue at Swallowing	Tongue at Rest
/a/	β = -0.53, z = -4.02, p<0.001	β =-0.45, z = -3.67, p<0.001
/i/	β = -0.52, z = -3.97, p<0.001	β = -0.21, z = -1.64, p<0.001
/u/	β = -0.59, z = -4.03, p<0.001	β = -0.44, z = -3.71, p<0.001

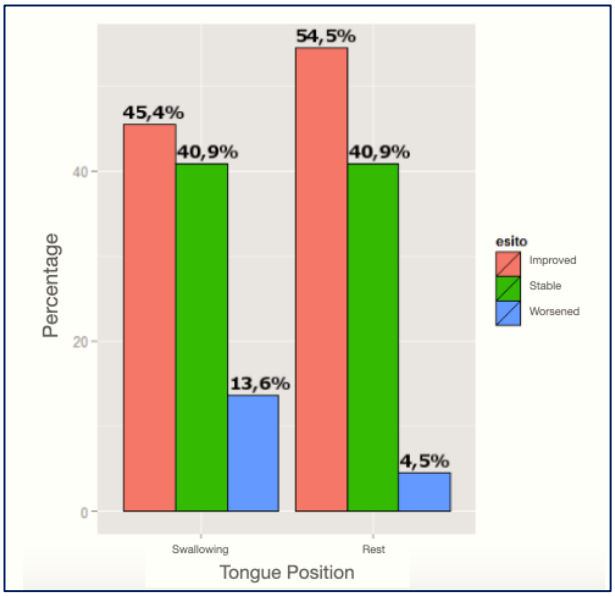

Figure 6. Patients with improved, stable, or worsened lingual positions following surgery distinctly for the two lingual positions of swallowing and resting.

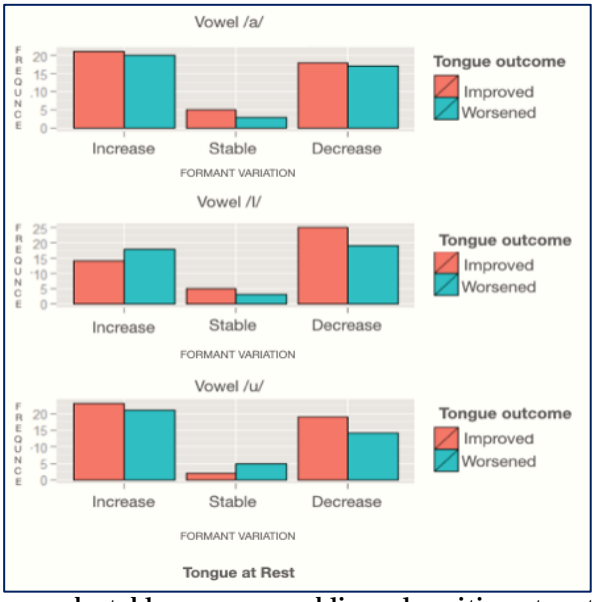

Figure 7. Patients with improved, stable, or worsened lingual position at rest following surgery related to formant variation.

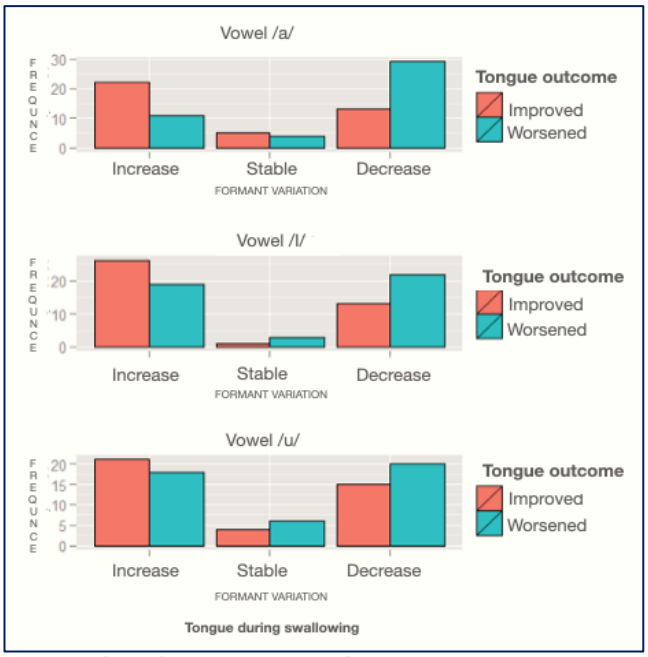

Figure 8. Patients with improved, stable, or worsened lingual position at swallowing following surgery related to formant variation.

Stereognosis; Oro-Facial Sensory and Muscle Functionality

Results coming from the qualitative analysis are shown in Figure 9. Overall, the percentage of patients displaying alterations in tongue position at rest (77.8%), tongue position while swallowing (59.3%), and breathing (51.8%) at T0 had been reduced at T1 (33.3%; 25.9%; and 14.8%, respectively) and T2 (28%; 23%; 14.8%). However, oral and perioral sensibility got worse at T1 and improved at T2, although not completely. This could be partially explained by the anesthetic effect on both tissues and oral mucosa, which tended to alter proprioception, but it goes to wear off over time (Figure 8). Stereognosis capacity, on the other hand, is not involved in this deterioration.

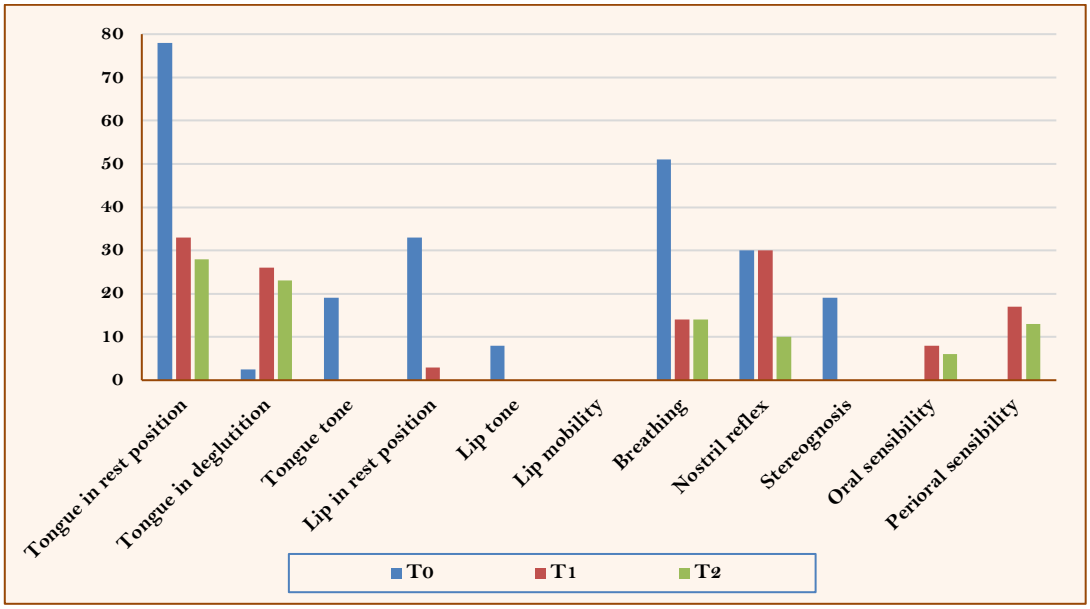

Figure 9. Graphical representation of the clinical evaluation of oral, perioral and stereognosis sensitivity and muscle functionality.

Discussion

Aside from the correction of dentofacial deformities, orthognathic surgery can change the orofacial function [27,28]. The larynx generates a spectrum of sound frequencies, and the maxillomandibular structure has an important role in shaping and modulating the resonance of the voice [29]. However, contradictory reports are available on voice quality following changes to the sagittal position of the maxilla and mandible [30,31]. Hence, the aim of the study is to investigate the effects that orthognathic surgery (maxillary or mandibular advancement or mandibular set-back) can have on the voice quality and articulation of speech, using integrated evaluation methods (spectrographic and perceptive-logopedic).

According to the results obtained, orthognathic surgery alters the formant frequencies (F1 and F2) of the main vowels. In particular, most patients from all three groups displayed an increase in F1 frequency in the pronunciation of the vowel /a/ (neutral articulation). However, F2 diminished only in G2, a result compatible with the skeletal displacement achieved by mandibular advancement, which causes the lingual posture to settle in a less backward position and the length of the vocal tract to increase [32] (F2 diminishes in relation to an elongation of the vocal tract) [33].

Conversely, for the vowel /i/ (closed anterior articulation), F1 decreased after advancement of both the upper and lower jaw, but increased after mandibular setback. Indeed, for the vowel /i/, F1 is almost completely determined not only by the narrowest section of the oral cavity but also by the volume of the posterior chamber. In contrast, a clear increase of F2 was observed in the majority of patients who underwent mandibular advancement, an operation that increases the anterior space, which is generally narrower than the posterior space when the vowel /i/ is pronounced.

Furthermore, even alterations for the vowel /u/ (closed posterior articulation) generally reflect the surgery received. Indeed, the majority of lower jaw advancement patients showed an increase of F1, which tended to be reduced in setback patients. As a matter of fact, the variation in vowel /u/ of F1 can be explained by a combination of both the widening of the anterior oral cavity and the narrowing of the bucco-pharyngeal cavity (to the rear) achieved by advancement surgery. Similarly, likely, the reduced values of F2 seen in both advancement groups (G1 and G2) can be ascribed to the reduction in the volume of the posterior cavity [34-38]. Likewise, the increase of F2 seen in G3 is likely to be linked to the reduction in the pharynx airway space provoked by setback surgery [33].

Concerning vocal defects perceived by the experts before surgery (T0), they had disappeared in half of the patients a month after the operation. Indeed, improving the anatomy and morphology of the oral cavity (the end part of the vocal tract) can determine a clearer and cleaner voice. Accordingly, six months after surgery, the voice was perceived to normalize, probably linked to the soft tissues regaining their elasticity and sensitivity. On the other hand, only a few patients perceived a modification of their own voice or generic vocal problem following an orthognathic surgical operation. However, this apparent discrepancy between the subjective and semi-objective results can be explained if we consider both the intrinsic limitations of the so-called "sensory" methodologies (intra-subjective variability) and the fact that the subjective analysis relied on retrospective data for some items.

Analysis of the tongue position after surgery showed that once the malocclusion had been corrected the position of the tongue improved during swallowing in about half of the patients, without any speech therapy, as reported even by Kagawa et al. [39]. Although the tongue behaves more naturally, however, it fails to adopt a completely normal posture. In fact, in several cases in which interdentalization at rest and complex lingual thrust during deglutition had been observed at T0, dental contact was observed at rest and during deglutition at T1.

Furthermore, in some cases, clinical examination before surgery revealed alterations in both tongue posture and breathing, which approached normal but did not disappear completely at T2. Indeed, surgery at least partially restored oral morphology. Accordingly, an improvement in stereognosis was noted even at T1 in all patients. This highlights the important role of the oral cavity, together with the position of the tongue inside it, in determining stereognosis.

However, it should be noted that across the sample patients reported a worsening in both oral and perioral sensitivity at T1, followed by only modest recovery six months after the operation. This may be due to an alteration in sensitivity, especially that conveyed by the inferior alveolar nerve, which can occur after orthognathic surgery.

Due to the fact that it could be considered a pilot study with preliminary results, the sample size was not performed. Surely, the small sample of patients analysed represents a limit for this study, and future analysis with a larger sample will be able to clarify even better the phonetic alterations caused by orthognathic surgery, including also patients who performed bimaxillary surgery. However, according to the obtained results, it has emerged that the vocal quality after surgery improves in a consistent way. The surgical intervention certainly improves the shape, settles it and adapts the function, but alone does not normalize it. Therefore, it is important to consider that the habit of static and dynamic lingual malposition and oral or mixed breathing, persisting for many years and therefore well consolidated in adults, are more resistant to a neuromotor reorganization only after orthognathic surgery. As a result, no guarantees of improvement can be given to patients undergoing orthodontic or orthognathic correction of malocclusion [40].

Conclusion

Our results highlight the importance of integrating pre- and post-operative speech assessment and speech therapy into orthognathic surgery protocols, in order to maximize the improvement obtainable by them. Indeed, although surgery seems to substantially improve vocal quality in patients treated surgically for skeletal malocclusion, with their voices becoming much clearer once the malocclusion has been resolved, outcomes will vary in relation to the direction of the jaw displacement undergone. Furthermore, although the oral function adapts to the improved shape of the hard and soft tissues achieved by surgery, it will not normalize without further intervention. Consequently, the null hypothesis is in the major part rejected, therefore it is advisable to include an evaluation and a pre- and post-surgery logopedic treatment along with the surgery itself.

Authors' Contributions

MP	https://orcid.org/0000-0001-6198-3053	Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review and Editing and Visualization.
EM	https://orcid.org/0000-0003-4023-6889	Data Curation and Writing - Review and Editing.
EP	----	Conceptualization, Validation, Investigation, Writing - Review and Editing and Visualization.
FN	----	Formal Analysis, Data Curation and Writing - Review and Editing.
TM	----	Data Curation and Writing - Review and Editing.
PS	----	Formal Analysis, Data Curation and Writing - Review and Editing.
UB	----	Formal Analysis, Data Curation and Writing - Review and Editing.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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