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# Acoustic analysis of vowel sounds before and after orthognathic surgery

Jaemyung Ahn [a,1], Gunjong Kim [a,2], Young Ho Kim [b,3], Jongrak Hong [a,*]

[a] Department of Oral and Maxillofacial Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, 50 Irwon-dong, Gangnam-gu, Seoul 135-710, Republic of Korea

[b] Department of Orthodontics, Samsung Medical Center, Sungkyunkwan University School of Medicine, 50 Irwon-dong, Gangnam-gu, Seoul 135-710, Republic of Korea

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ABSTRACT

The purpose of this study was to compare the articular structures and vowel sounds of patients with mandibular prognathism before and after bilateral sagittal split ramus osteotomy (BSSRO). Eight patients who underwent BSSRO to correct mandibular prognathism were selected for inclusion in this study. All patients were asked to read short words (vowels), and these sounds were recorded. Every utterance was repeated twice in four different sessions before the operation and at 6 weeks, 3 months, and 6 months after the operation. The data were analysed using Praat (ver. 5.1.31), and the formant frequencies (F1, F2) of the eight vowels were extracted. PlotFormant (ver. 1.0) was used to draw formant diagrams. The F1 and F2 of front–low vowels were reduced after BSSRO, and the articulating positions of the patients shifted in a posterior–superior direction after the procedure. Additionally, the area of vowel articulation was dramatically reduced after BSSRO but increased slowly over time.



## 1. Introduction

Although the primary goal of orthognathic surgery is to restore the normal occlusion and aesthetic appearance of the face, functional improvements in mastication and pronunciation are also important outcomes. Previous research regarding pronunciation has focused on patients with maxillofacial deformity with structural deficiencies, especially cleft lip and palate. However, studies that focus on structural changes in the oral cavity and the pharynx due to orthognathic surgery are very rare in patients without structural deficiencies. Bilateral sagittal split ramus osteotomy (BSSRO) affects the position of the tongue, teeth, and lips, all of which have important roles in pronunciation. Because of the difficulty of conducting direct research on pronunciation, dental specialists have proposed an indirect procedure that uses the position of the hyoid bone on cephalometric lateral radiography and affects the airway in the retropharyngeal space (Eggensperger et al., 2005; Kawakami et al., 2005; Jorge et al., 2009; Marsan et al., 2010). Additionally, although computerised tomography and three-dimensional reconstruction have recently been recommended, previous studies have offered only general ideas about how the vocal tract is expected to change and have been limited by the assumption that this procedure, like previous methods, may cause changes in pronunciation. Moreover, although it has been shown that the hyoid bone, which is moved to a posteroinferior position as a result of the operation, returns to its original position, this change in the hyoid bone is not consistent with the objective goal of reconstructing the structure of pronunciation through orthognathic surgery.

Previous analytical methods employed in the field of phonetics have relied on the auditory impressions of researchers, and few trained professionals are able to perform these analyses, rendering the results prone to the effects of subjectivity. In the early 20th century, Miller, Stumpf, Paget, and other researchers developed the Helmholtz resonance theory and identified the roles of formant structure. Additionally, Ladefoged proposed using acoustically measured values instead of the height of the tongue to demonstrate auditory qualification when analysing vowel qualification (Ladefoged, 1975). As a result, objective and standardised research methods that used a formant structure with acoustic indicators were developed for use in vowel analysis.

Lindblom and Sundberg found that F1 is affected by the patency degree of the jaw and that F2 is affected by the

* Corresponding author. Tel.: +82 2 3410 2420; fax: +82 2 3410 0038.
*E-mail addresses:* awilltowin@gmail.com (J. Ahn), gun-jong@hanmail.net (G. Kim), huyyoung@skku.edu (Y.H. Kim), hongjr@skku.edu (J. Hong).
[1] Tel.: +82 2 3410 2420; fax: +82 2 3410 0038.
[2] Tel.: +82 10 9933 5297.
[3] Tel.: +82 2 3410 2425.

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movement of the tongue. They asserted that there was an intimate relationship between articulatory and acoustic factors (Lindblom and Sundberg, 1971). Clark and Yallop proposed that formant formation could be used for the analysis of acoustic characteristics based on the shape of the mandible and tongue (Clark and Yallop, 1995). Dalston and colleagues studied the pronunciations recorded by 40 females who had previously undergone orthognathic surgery and asked three linguists and language pathologists to classify each according to hypernasality, hyponasality, and pronunciation proficiency. Thus, this research was very subjective, and it relied on auditory qualification (Dalston and Vig, 1984; Lee et al., 2002; O'Gara and Wilson, 2007). Subsequently, Bowers and colleagues studied the changes before and after orthognathic surgery using cephalometric lateral radiography and formant analysis. Although their work made important contributions to research methodology, their results were insignificant as they were based on only five patients (two with class III malocclusion and three with class II malocclusion according to Angle's classification), which did not provide sufficient power to support their theory. Their study also did not provide guidelines regarding how to actually perform orthognathic surgery (Bowers et al., 1985). Using formant analysis, Niemi et al. analysed vowel changes by measuring F0, F1, and F2 values and studied samples of five class II malocclusion patients (one of whom also simultaneously underwent a Le Fort I osteotomy) who underwent BSSRO (Niemi et al., 2006). Each of these five patients showed visible changes in a formant graph. According to Niemi et al., compensatory movements of the tongue and mandible enabling normal incisor relations could occur in patients with class II malocclusion, and no significant changes in pronunciation were observed after mandibular advancement. However, this outcome may not be relevant to patients with class III malocclusion, and only a few studies of the structural changes in pronunciation and articulation after a mandibular setback have been conducted, there is no consensus on the effects of mandibular setback on the speech and voice (Fairbanks and Lintner, 1951; Hassan et al., 2007; Mishima et al., 2013). According to the author's previous study, patients with Angle's class III malocclusion showed a larger aperture for low vowels and a forwarding of the back vowels compared with occlusion patients. This study also found a distinctive usage of a vertically wider and horizontally narrower area for vowel triangles. It was hypothesised that this accounted for changes in the pronunciation structure after surgery, but further research related to gradation after surgery is needed (Kim et al., 2009).

The purpose of this study was to analyse the structure and the changes in pronunciation after BSSRO to identify how surgery produces structural changes that affect the pronunciation and articulation of patients with mandibular prognathism.

## 2. Patients and methods

### 2.1. Subjects

This study included eight symptomatic male patients aged 18–26 years (mean 21.9) with class III malocclusion who had previously undergone BSSRO at the Department of Oral and Maxillofacial Surgery at Samsung Medical Center and eight patients in their twenties with class I malocclusion who used standard-language. None of these patients had a previous phonetic medical history or hearing or perception problems that could interfere with the pronunciation analysis.

A mandibular fracture and a semi-rigid fixation method with a titanium plate and screws were used. All operations in this study were performed by a single surgeon.

### 2.2. Methods

#### 2.2.1. Recording

The recording apparatus consisted of an AKG Acoustics C420 headset microphone (Harman, Vienna, Austria) on a PMD 670 recorder (Marantz, Tokyo, Japan). A distance of 10 cm was maintained between the mouth and the headset microphone for each recording. The recordings were performed in a soundproof room at the Vestibulocochlear Laboratory in the Samsung Medical Center (Fig. 1).

The vowel list for the pronunciation check procedure consisted of [a], [e], [i], [o], [u], [ʌ], [æ], and [u:]. These eight single vowels were added to the consonant [d] so that a consonant + vowel (CV) configuration could be developed. After this addition, the words [da], [de], [di], [do], [du], [dʌ], [dæ], and [du:] were randomly displayed on a screen to minimise the intonation gap between the standard-language and the dialect speakers. The screen showed each word twice, and the speakers read the words aloud. The speed of the subjects' reading was intentionally set at moderate levels by displaying each word after a 2.5 s pause.

The recordings were first performed after the orthodontic treatment prior to the operation and then at 6 weeks, 3 months, and 6 months after the operation.

#### 2.2.2. Analysis

*2.2.2.1. Formant abstraction.* Praat ver. 5.1.31 (Phonetic Sciences, University of Amsterdam, Netherlands) was used for all formant measurements (Fig. 2). The F1 and F2 values were abstracted at the stable stage of each vowel at a pre-set length of the analysis window, which was determined to be 0.025 s. To maximise the objectivity of this study, the Linguistics Department of Seoul National University provided consultation regarding formant abstraction.

*2.2.2.2. Formant graph.* On a formant graph, the horizontal dimension represents the aperture of the first formant (F1) and the vertical dimension represents the front–back movement of the second formant (F2). The vowel distribution chart, which presents a plot of articulation showing the positions and the heights of vowel sounds, and the formant graphs, which are based on acoustic results, are very similar in construction.

The formant graphs were created using PlotFormat ver. 10.0 (University of California, Los Angeles, USA), and the graphs were used to analyse the articulatory characteristics of the vowel distribution patterns (Fig. 1). The periodical formant graphs (at the pre-op orthodontic treatment and at 6 weeks, 3 months, and 6 months after the operation) were overlaid and used to visualise the vowel changes in each group. These graphs were also compared with the graphs of occlusion patients.

#### 2.2.3. Area of formant graph

The area of each formant graph on a formant plane was calculated; the horizontal dimension was used to represent the first formant (F1), and the vertical dimension was used to represent the second formant (F2) to elucidate the changes following surgery. Each triangular area was assessed based on the distance between vowels and was summarised as the total value of the formant graph.

The following formulae were used to assess the formant graphs: the distance between two points, $(x_1, y_1)$ and $(x_2, y_2)$ on the graph $= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$, and the lengths of three sides of a triangle are $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c} = \sqrt{s(s-a)(s-b)(s-c)}$ $\left(s = \frac{a+b+c}{2}\right)$.