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Original Article

Perceptual and videofluoroscopic analyses of relation between backed articulation and velopharyngeal closure following cleft palate repair

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ABSTRACT

Purpose: Perceptual and videofluoroscopic (VF) analyses were performed to analyze velopharyngeal (VP) closure motions and tongue backing movement in subjects with postalveolar, palatal, and velar backed articulation (BA).
Materials and methods: For perceptual analysis, the timing of the appearance of BA and the VP closure level of 22 children with BA following palatal repair were compared to those of 17 subjects with normal articulation, 17 subjects with lateral articulation, and 11 subjects with glottal stop. For VF analysis, 16 subjects with BA and two healthy adult males as references were enrolled. On VF images, the proportions of the time required to complete VP closure and the duration of articulation (VPC/DA) were recorded and then analyzed based on the various degrees of tongue backing movement.
Results: The appearance of BA was recognized just after the acquisition of VP closure, and it was later than that of glottal stop and earlier than lateral articulation. On VF images, VP closure was achieved before tongue movement in healthy individuals, but after tongue movement in BA subjects. VPC/DA on articulation of both /ta/ and /sa/ were significantly smaller for healthy individuals than for BA subjects ($P < 0.05$). The timing of the complete VP closure approached that of articulation when the site of articulation shifted posteriorly ($P < 0.01$).
Conclusions: BA may result from precedent tongue backing movement before the completion of VP closure, as a process that may assist the VP closure motion for articulation.

1. Introduction

Patients with cleft palate (CP) have various problems, such as feeding, developmental disorders, resonance disorders, otolaryngological disease, dental anomalies, and psychosocial disorders [1,2]. The association of speech disorder, one of the problems, with CP has been well documented. Golding-Kushner [3] stated that speech production requires three valves: the glottis at the laryngeal level, velopharyngeal (VP) region, and oral region. The VP area acts to separate the nasopharynx from the oropharynx, and it has special importance for resonance and articulation. As the soft palate plays an important role in the VP closure mechanism, which allows a speaker to differentiate between nasal and oral speech sounds, CP patients with an insufficient VP closure mechanism will sound hypernasal and experience nasal air emission [4]. Therefore, such patients will find it difficult to produce pressure consonant sounds, such as plosives and fricatives, and many develop compensatory articulations.

Cleft-related articulation disorders are categorized into active and passive [5]. The former are specific articulatory gestures that replace intended consonants, and the latter are thought to be the product of structural abnormality or dysfunction. Active cleft-related compensatory articulations are characterized as posterior placements of the target sounds toward the vocal tract [6,7]. They

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include glottal and pharyngeal stops to replace plosive sounds, pharyngeal fricatives to replace postalveolar fricatives, and nasal fricatives to replace alveolar fricatives. Backed articulation (BA), backing or posterior shifting of the site of articulation, is also one of the most common cleft-related abnormal articulations [6,7]. Based on the International Phonetic Alphabet 2005 (IPA 2005) [8], this kind of articulation is classified into the mid-dorsum palatal stop, mid-dorsum palatal fricatives, velar stop, and velar fricative. Possible causes of BA, such as palatal fistula [9,10], abnormal palatal morphology or dental arch [11–14], and velopharyngeal insufficiency (VPI) [15], have previously been discussed. However, the mechanism of BA occurrence after the surgical repair of CP is not well understood.

When considering the mechanism of human phonation, it is well known that: (1) before phonation, the soft palate is elevated and comes into contact in an air-tight manner with the posterior wall of the pharynx, (2) separating the oral from nasal cavity, (3) then movements of the articulatory organs follow to increase the intraoral pressure, and (4) voice is produced as the accumulated energy is released [16]. Warren [17] reported that, during human phonation, the elevation of the soft palate before phonation is learned by a feedback system using aerodynamic elements such as the intraoral pressure. He mentioned that the system's function was based on a system in which every attempt was made to regulate pressure within the vocal tract. In this model, loss of pressure in one part of the vocal tract leads to increased pressure in another part [3]. From these previous descriptions, it is thought to be meaningful to dynamically observe tongue motion while targeting consonants, which can affect the intraoral pressure by anteroposterior movement, and VP closure motion for achieving VP closure, in order to analyze the cause of postalveolar, palatal, and velar BA.

The purpose of this study was to analyze VP closure motions and tongue backing movement by means of perceptual and videofluoroscopic (VF) analyses in subjects with postalveolar, palatal, and velar BA.

2. Materials and methods

This study was approved by the Research Ethical Review of Kagoshima University Medical and Dental Hospital (Kagoshima University Hospital) (#22-122) and Kyushu University Medical and Dental Hospital (Kyushu University Hospital) (#23-65). All data in this study were collected from the records of the CLP team at Kagoshima University Hospital and the CLP team at Kyushu University Hospital. Because the senior author and the senior speech-language hearing therapist (ST) moved from Kyushu University Hospital to Kagoshima University Hospital in 2005 and 2009, respectively, two institutions were engaged in this study.

The study consisted of two parts: (1) perceptual analysis of the timing of VP closure acquisition and BA occurrence using the subjects in the CLP Clinic at Kyushu University Hospital and (2) VF analyses of the relation between BA and VP closure using the subjects in the CLP Clinics at Kyushu University Hospital and Kagoshima University Hospital.

2.1. Perceptual analysis of the timing of VP closure acquisition and BA occurrence

Twenty-two Japanese children who underwent palatal repair for CP at the Department of Maxillofacial Surgery, Kyushu University Hospital, and exhibited backing of alveolar targets to the palate or velum were enrolled in the perceptual analysis of the timing of VP closure acquisition and appearance of palatal or velar BA (Table 1). For comparison, the additional data from perceptual analysis of 17 subjects with normal articulation, 17 subjects with lateral articulation (LA), and 11 subjects with glottal stop (GS) were also used (Table 1). None of the subjects demonstrated any syndromes, cognitive disability, and/or hearing impairment.

Table 1
Sample description for perceptual analysis of appearance of various articulations.

No. of subjects with palatal/velar BA	22
Gender	
Male	12
Female	10
Cleft type	
UCLP (%)	16 (73)
BCLP (%)	5 (23)
CP (%)	1 (4)
No. of subjects with other articulations	
Normal articulation	17
Lateral articulation	17
Glottal stop	11

For all subjects, palatal repair was carried out with the same technique using a modified pushback surgery, which allowed conservation of part of the periosteum in the anterior part of the maxilla and elongation of the retroposition of the levator veli palatine muscles at an age of around 1.5 years.

Speech assessment was performed by an experienced ST every 3 months from just after palatoplasty to around 4 years old, in which speech assessment generated reliable speech outcomes. VP closure was comprehensively assessed by oral-peripheral examination, perceptual assessment, articulation testing, exhalation examination, the mirror test, nasometer testing, and cephalogram examination [18]. Based on the data from perceptual and instrumental assessments, overall VP closure was classified into three categories: good, mild, and poor. Our criteria for the classification of VP closure were as follows [19]:

(1) *Good VP closure*: Hypernasal voice was not present, nasal emission during blowing and phonating vowels and consonants was 0–1 cm in the mirror test, and mean nasalance scores of the above speech stimuli were <20%.
(2) *Mild VP closure*: Slight hypernasal voice was observed, nasal emission during blowing and phonating vowels and consonants was 1–2 cm in the mirror test, and the mean nasalance scores varied from 20% to 40%.
(3) *Poor VP closure*: Severe hypernasal voice was observed, nasal emission during blowing and phonating vowels and consonants was >2 cm in the mirror test, and the mean nasalance scores were >40%.

Articulations were evaluated using the articulation test of the Japan Society of Logopedics and Phoniatrics, and then converted to IPA 2005 [8] phonetic symbols so that all abnormalities could be diagnosed and transcribed in IPA. Articulation and consistency errors were observed by perceptual and visual assessment and recorded.

To analyze the timing of VP closure acquisition and appearance of abnormal articulations, including BA, LA, and GS, the changes in the mean VP closure score every 6 months during the postoperative course and the mean age at the occurrence of each articulation disorder were evaluated. The VP closure score was defined as good = 3, mild = 2, and poor VP closure = 1, and the mean VP closure score for subjects with each articulation disorder was calculated.

2.2. VF analyses of the relation between BA and VP closure

2.2.1. VF observation of the site of articulation

For VF analysis, observation of the site of articulation was performed using lateral VF image sequences of 16 subjects who