Original Article

Changes in Horizontal Jaw Position and Intraoral Pressure

Jun-ichi Takada[a]; Takashi Ono[b]; Shigeki Takahashi[c]; Ei-ichi Honda[d]; Tohru Kurabayashi[e]

ABSTRACT

Objective: To determine the effect of an imbalance in buccolingual pressure that may be involved in molar dental compensation in the mandible and asymmetry of the dental arch in subjects with facial asymmetry.

Materials and Methods: We performed simultaneous measurement of the buccolingual pressure on the mandibular right first molar when subjects without facial asymmetry experimentally shifted the mandible laterally. Buccolingual pressures in the rest position (RP), right-shifted position (RS), and left-shifted position (LS) were compared. Moreover, T1-weighted magnetic resonance images were obtained in RP, RS, and LS.

Results: Tongue pressure tended to decrease in the order LS $>$ RP $>$ RS, while cheek pressure tended to increase in the order LS $<$ RP $<$ RS. The tongue/cheek pressure ratio tended to decrease in the order LS $>$ RP $>$ RS. There were significant positive (in RS) and negative (in LS) correlations between displacement of the tongue and tongue pressure.

Conclusions: This imbalance in buccolingual pressures in the laterally-shifted mandibular position may partly explain molar dental compensation in the mandible and asymmetry of the dental arch in subjects with facial asymmetry.

KEY WORDS: Horizontal jaw position; Intraoral pressure; Facial asymmetry

INTRODUCTION

It is thought that neighboring soft tissue influences the shape of the dental arch and the position of the teeth. Pressure exerted by the tongue and cheek has been reported to be especially important.[1–4] Weinstein and colleagues[1] first measured intraoral pressure by installing sensors in the regions of the maxillary second premolar and first molar, and the maxillary anterior teeth. They found that the pressures from the tongue and lip were balanced, and proposed the so-called "equilibrium theory." Lear and Moorrees[2] installed sensors in the region of the bilateral maxillary and mandibular premolars and measured the long-term changes in buccolingual pressure during pronunciation, deglutition, mastication, resting, and changes in head posture in seven healthy subjects with normal occlusion. Thus, they noted that such pressure influenced the dental arch. Later, Proffit[3] reexamined the "equilibrium theory" in an experiment in guinea pigs and found that the pressure from the periodontal membrane, like the pressures from the tongue and cheek, also played an important role.

Practically, a spaced arch in the mandible has been described in subjects with lymphangioma,[4] whereas in the congenital aglossia, a narrowed arch has been reported.[5] Moreover, a lack of electromyographic activity of the masseter muscle, hypotonicity, and hypertrophy of the tongue are seen in subjects with Duchenne muscular dystrophy.[6] This indicates that an imbalance of power inside and outside of the dental arch may result in a remarkable change in the width of the dental arch.

In a statistical examination, Bandy and Hunter[7] reported that there was a positive correlation between the tongue volume and the perimeter of the mandibular arch in 39 men who had a full complement of mandibular teeth with the exception of the third molars. Recently, Tamari and co-workers[8] reported that there

[a] Research Fellow, Maxillofacial Orthognathics, Tokyo Medical and Dental University, Graduate School, Tokyo, Japan.

[b] Lecturer, Maxillofacial Orthognathics, Tokyo Medical and Dental University, Graduate School, Tokyo, Japan.

[c] Private practice, Hadano, Japan.

[d] Professor, Oral and Maxillofacial Radiology, Graduate School, University of Tokushima, Tokushima, Japan.

[e] Professor, Oral and Maxillofacial Radiology, Graduate School, Tokyo Medical and Dental University Tokyo, Japan.

Corresponding author: Dr Takashi Ono, Maxillofacial Orthognathics, Tokyo Medical and Dental University, Graduate School, 5-45, Yushima 1-chome, Bunkyo-ku, Bunkyo-ku, Tokyo 113-8549, Japan
(e-mail: t-ono.mort@tmd.ac.jp)

Accepted: May 2007. Submitted: February 2007.

 DOI: 10.2319/021207-69.1

were significant differences between the tongue volume and some parameters in the mandibular dental arch including the perimeter and arch width in 74 adults with normal occlusion. They also found that the correlations tended to be more significant in the more posterior part of the dental arch.

There are known to be differences in the shape of the dental arch and the position of molars between the shifted and nonshifted sides in subjects with facial asymmetry. Shigefuji and co-investigators[9] found that the buccolingual tooth axes of the shifted side in the maxillary and mandibular first molars were significantly different from those on the nonshifted side. They also reported that there was a significant correlation between the tooth axis of the maxillary molar on the nonshifted side and the amount of mandibular deviation, which suggests the existence of dental compensation in the frontal plane in response to skeletal deformity. Likewise, significant differences were found in the buccolingual tooth axes of the maxillary and mandibular molars between the shifted and nonshifted sides.[10] Moreover, a significant correlation was revealed between the buccolingual tooth axis of the mandibular molars on the shifted side and the amount of mandibular deviation.[11] Although the findings in these previous studies suggest that an imbalance in buccolingual pressure may be involved in the molar dental compensation in the mandible and asymmetry of the dental arch in subjects with facial asymmetry, this point has not yet been clarified.

Thus, in the present study we examined the hypothesis that tongue pressure decreases on the shifted side, but increases on the nonshifted side, while cheek pressure increases on the shifted side, but decreases on the nonshifted side.

MATERIALS AND METHODS

Subjects

This study was carried out in 12 skeletal Class I Japanese men with a mean age of 28 years (range: 25–31 years old). Subjects with known craniofacial anomalies and syndromes, clefting, temporomandibular joint dysfunction, dysphagia, or who were taking any medication known to affect muscle activity were excluded from the study. All of the subjects had complete dentition with the exception of the third molars. Each subject had a normal overjet and overbite. Written informed consent was obtained from each subject before the study.

Recording of Intraoral Pressure

Tongue and cheek pressures on the lingual and buccal surfaces of the mandibular right first molar were measured with a pair of pressure sensors (PS-05KC, Kyowa Co, Tokyo, Japan) incorporated in the buccolingual plates of a custom-made intraoral appliance (Figure 1A). Therefore, the two pressure sensors in the appliance could measure the pressure from the tongue and cheek when they touched. The thickness of the appliance and the location of the transducers were carefully standardized. Two cables led from the extraoral measuring system through the right oral rim to the pressure sensors, which kept the plastic plate very thin with only minimal disturbance of the cheek and tongue. In addition, four custom-made plates that covered maxillary and mandibular anterior teeth were made for each subject (Figure 1B). These anterior plates were used to register the right (RS) and left (LS) shifted position of the mandible of each subject. Both the appliance and plates were made using a plastic plate 0.75 mm thick (Imprelon S, Scheu-Dental Co, Iserlohn, Germany) following the method of Narita and colleagues.[12] The sensitivity of the sensor was calibrated before and after each experimental session. Pressure was measured at a sampling frequency of 100 Hz,[12] and acquired data were recorded with a personal computer by a warp measuring instrument (PCD-300A, Kyowa Co) and analyzed.

The subjects lay in a reclining chair in the supine position with nasal breathing. We allowed at least 5 minutes for an habituation period after the intraoral appliance was inserted.[12] Therefore, pressure sensors were in the state of no pressure, and the output value at that time was defined as the pressure at rest. Recordings were made for 20 seconds at three mandibular positions in the supine position, rest position (RP), RS, and LS. Intraoral pressure in RS and LS were recorded twice in random order with RP between both. In RS and LS, anterior plates were used to stabilize the mandibular position (Figure 1B). Subjects were not cued as to how to hold their tongue when completing the tasks. Five seconds were extracted at random from when the record from the pressure sensors in RP, RS and LS was steady, and the mean and the standard deviation (SD) of the intraoral pressure were calculated.

Magnetic Resonance Imaging

Horizontal magnetic resonance images (MRIs) of oral structures were taken to define the changes in the position of the tongue when the mandible was shifted laterally. An insoluble marker (length: 5 mm) containing ferric ammonium citrate was made. After the marker was attached to the tip of the tongue using cyanoacrylate adhesive, the subject was placed in a 1.5T MRI apparatus (Magnetom Vision, Siemens AG, Erlangen, Germany), which was equipped with a head

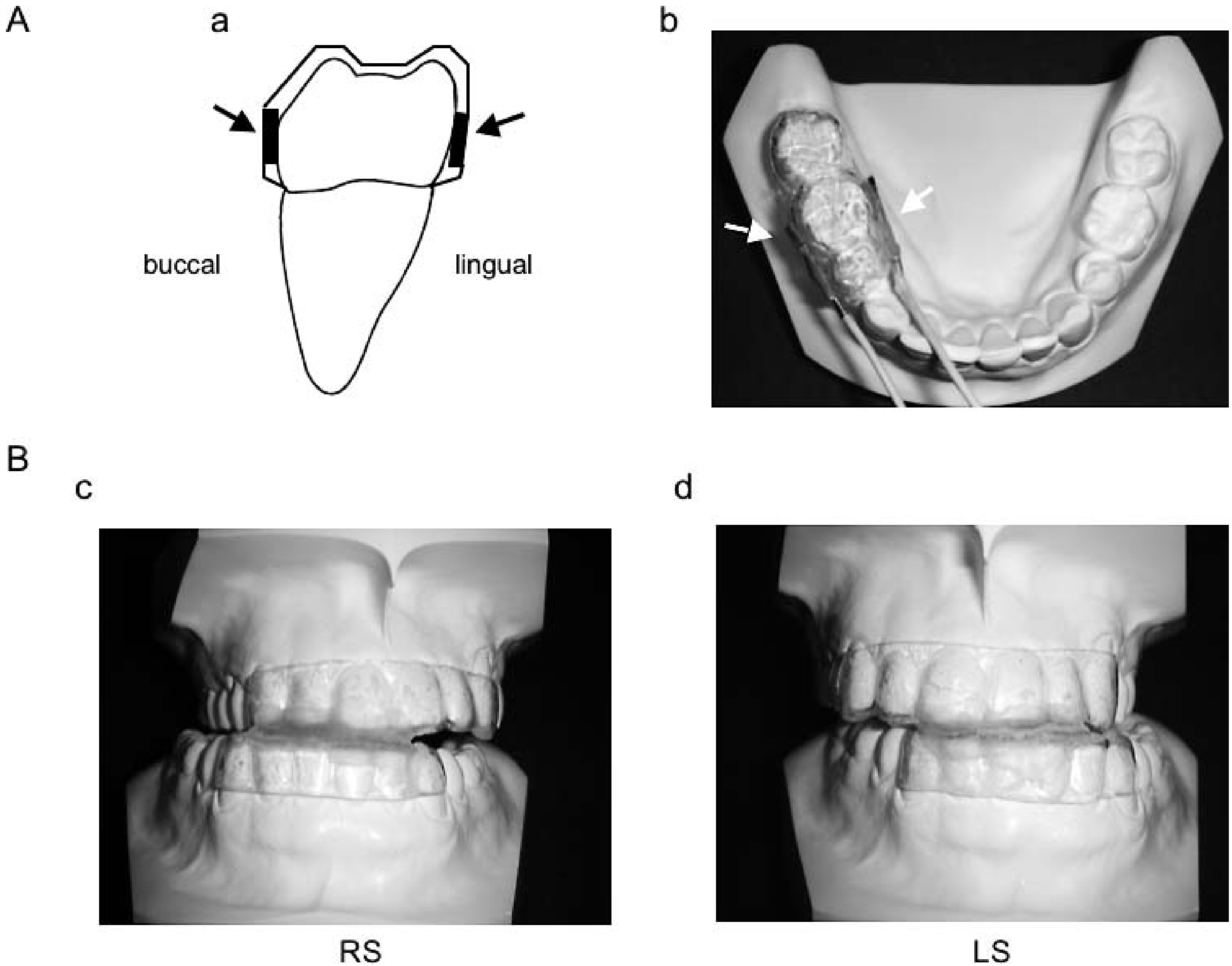

Figure 1. Location of pressure sensors and registration of shifted mandibular positions. (A) Two sensors are used for the right molar region (arrows). (a) Coronal view. (b) Occlusal view. (B) Frontal view of a custom-made intraoral appliance for the shifted position of the mandible to the (c) right and (d) left. RS indicates right-shifted position; LS, left-shifted position.

coil. The subject's head was stabilized with a solid foam cushion. T1-weighted images were obtained in RP, RS, and LS (Figure 2). In RS and LS, anterior plates were used. During the acquisition of images, the subject was instructed to breathe through the nose and not to swallow. MR images in RP and RS and LS were superimposed and the displacement of the tongue was measured. Moreover, the displacement of the mandible was measured using the mandibular incisors as a reference.

Statistical Analysis

The Friedman test and Student-Newman-Keuls test were used to determine whether there were significant differences in intraoral pressure and the ratio of tongue pressure to cheek pressure in the three mandibular positions. A Spearman correlation coefficient by rank was used to evaluate the relationships between amounts of displacement of the mandible and tongue. All procedures were performed with commercial statistical software (Excel 2003, Microsoft, Redmond, Wash).

RESULTS

Changes in Tongue and Cheek Pressure in RP, RS, and LS

Mean and standard deviation in tongue and cheek pressure in RP, RS, and LS in the 12 subjects are shown in Figure 3. Tongue pressure was greater than cheek pressure in all (92%) 11 subjects in RP. On the other hand, cheek pressure was greater than tongue pressure in all (100%) 12 subjects in RS, whereas tongue pressure was greater than cheek pressure in all (100%) 12 subjects in LS.

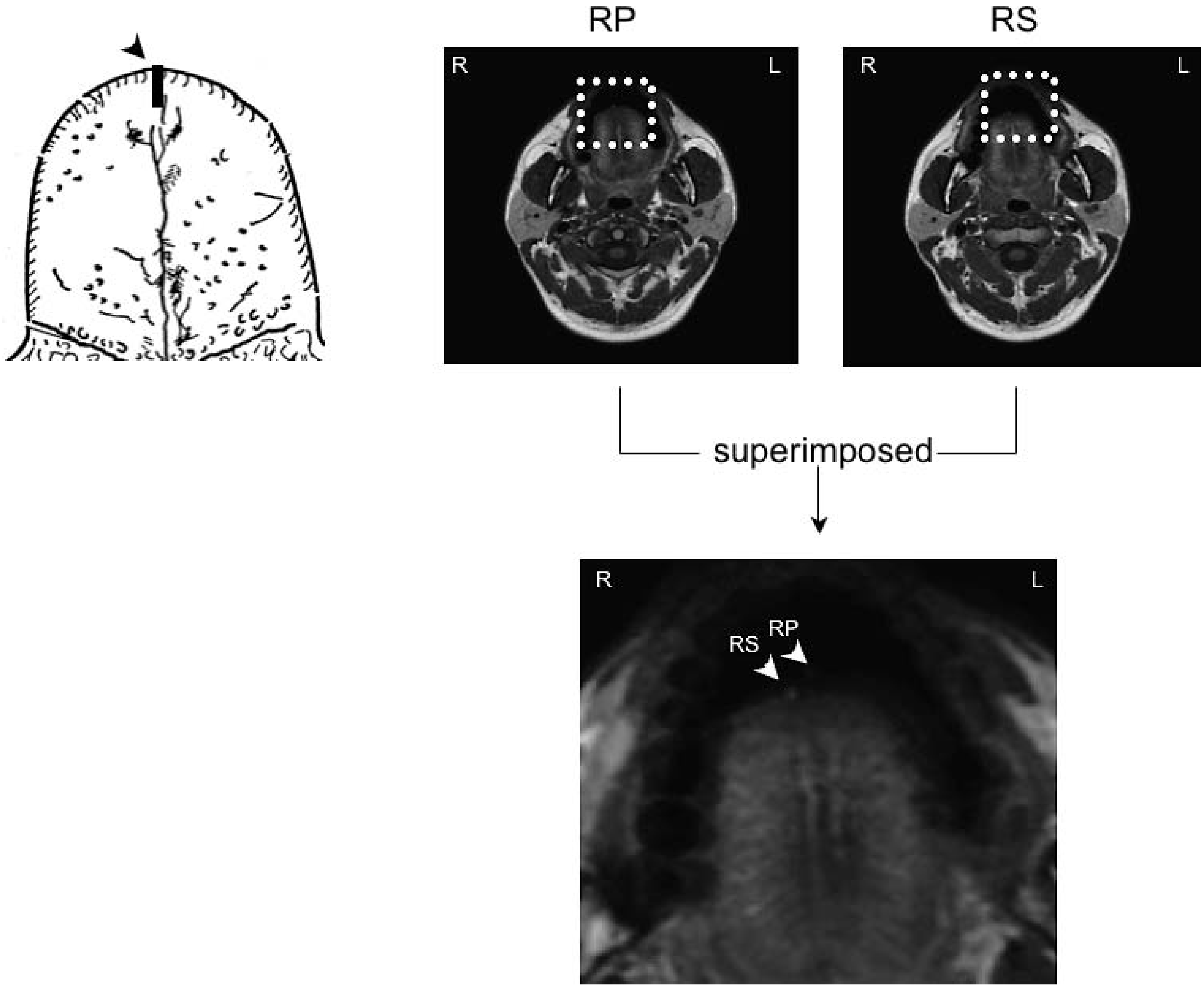

Figure 2. Determination of the displacement of the tongue in the shifted position of the mandible on magnetic resonance images. Arrowheads indicate the location of the marker. RP indicates rest position; RS, right-shifted position.

Changes in tongue pressure in the three mandibular positions for the 12 subjects are illustrated in Figure 4A. Tongue pressure tended to decrease in the order LS > RP > RS. There were significant differences between LS and RP ($P < .05$) and LS and RS ($P < .01$). Changes in cheek pressure in the three mandibular positions for the 12 subjects are illustrated in Figure 4B. Cheek pressure tended to increase in the order LS < RP < RS. There were significant differences between LS and RP ($P < .05$), RP and RS ($P < .05$), and LS and RS ($P < .01$). Changes in the tongue/cheek pressure ratio in the three mandibular positions in the 12 subjects are illustrated in Figure 4C. The tongue/cheek pressure ratio tended to decrease in the order LS > RP > RS. There were significant differences between LS and RP ($P < .05$) and LS and RS ($P < .01$). Interestingly, the tongue/cheek pressure ratio in RP was almost identical (1.6 ± 0.2 [mean ± SD]) in the 12 subjects.

Relationship Between Displacement of the Tongue and the Mandible

In RS, the amount of displacement of the tongue was 3.55 ± 3.21 mm (mean ± SD), whereas that of the mandible was 8.26 ± 0.58 mm. On the other hand, in LS, the amount of displacement of the tongue was 5.95 ± 5.82 mm, whereas that of the mandible was 8.17 ± 0.6 mm. Data from all 12 subjects are plotted in Figure 5. There were no significant differences between the displacement of the tongue and the mandible in either RS (Figure 5A) or LS (Figure 5B).

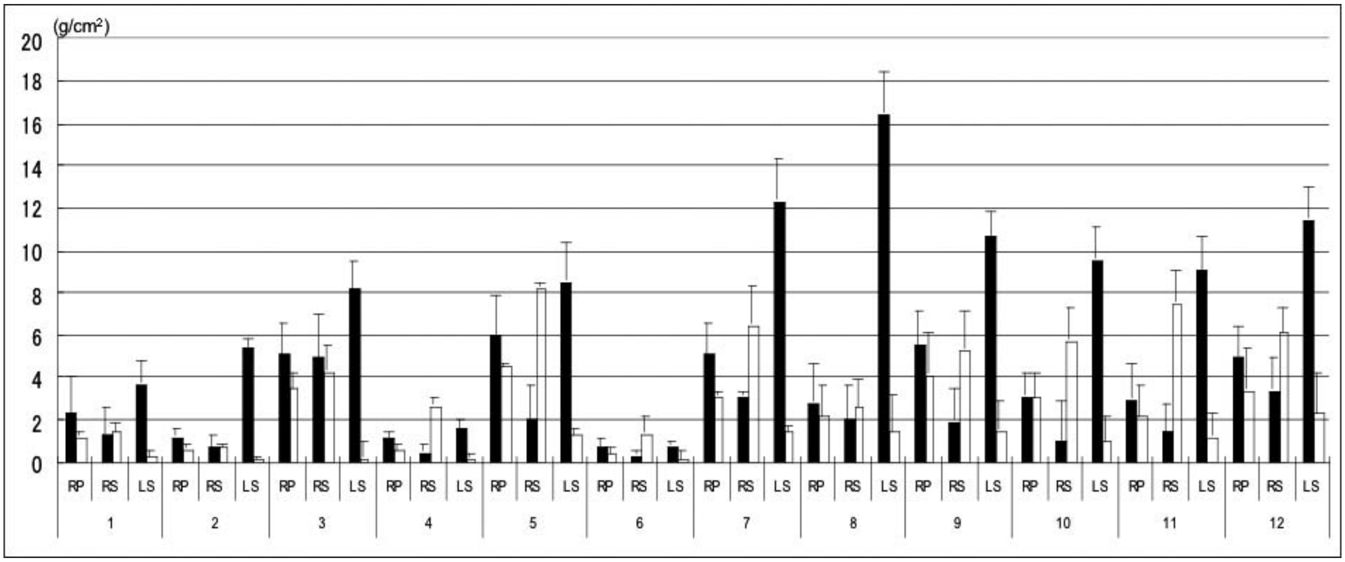

Figure 3. Individual intraoral pressures in the three mandibular positions in the 12 subjects. Mean and standard deviation are depicted. Solid and open bars indicate the tongue and cheek pressures, respectively. RP indicates rest position; RS, right-shifted position; LS, left-shifted position.

Relationship Between Displacement of the Tongue and Tongue Pressure

The relationship between displacement of the tongue and tongue pressure for the 12 subjects is shown in Figure 6. There was a significant positive correlation between displacement of the tongue and tongue pressure in RS (Figure 6A; $P < .05$). Likewise, there was a significant negative correlation between displacement of the tongue and tongue pressure in LS (Figure 6B; $P < .01$).

DISCUSSION

Measuring Method

Intraoral pressure has mainly been measured with a pressure sensor that measured mechanical warping. Recently, a pressure sensor that measured hydraulic pressure was placed on the maxillary and mandibular premolars and the molar region, and the palate, to measure intraoral pressure not only during rest, but also during deglutition and chewing.[13–15] Compared with a traditional pressure sensor that detects mechanical warping, the pressure sensor uses hydraulic pressure and is advantageous in that its size does not disturb oral function and negative pressure can also be measured. In the present study, the same micro pressure sensor was used as in the study by Narita et al[12] because (1) the sensor was the thinnest[16] currently available, (2) the average buccolingual pressure at the mandibular molar was positive at rest, and (3) we did not measure pressure under oral functional conditions when the sensor could become obstructive. When the warp due to pressure of the micro pressure sensor was measured under a constant temperature of 20°C and 36°C, a stable relation was found.[12] Therefore, it was thought that measurement during rest rather than during function was possible.

In this study, the average tongue pressure was 3.44 $\pm$ 1.86 g/cm^2 (mean $\pm$ SD), and the average cheek pressure was 1.87 $\pm$ 1.38 g/cm^2 at RP. The average tongue pressure was similar to the resting value (2.8 g/cm^2) measured at the mandibular first molar region in the previous study.[12] Moreover, these values were approximately equal to the respective tongue (2.41 $\pm$ 3.34 g/cm^2) and cheek (2.01$\pm$ 3.01 g/cm^2) pressures measured with a sensor that used hydraulic pressure.[15] Furthermore, the cheek pressure is commonly smaller than the tongue pressure.[2,15] Thus, it is thought that the measuring method in this study was comparable to those in previous studies. On the other hand, no previous studies investigated buccolingual pressures when the mandible was shifted laterally.

There were significant differences in cheek pressure between LS and RP ($P < .05$), LS and RS ($P < .01$), and LS and RS ($P < .01$). Meanwhile, there were significant differences only between LS and RP ($P < .05$) and LS and RS ($P < .01$) in tongue pressure and the tongue/cheek pressure ratio. This difference may be attributable to our experimental set-up, in which the pressure sensor was only installed in the right mandibular molar region. Thus, the increase in cheek pressure appeared more clearly than the decrease in tongue pressure when the mandible was shifted from RP to RS.

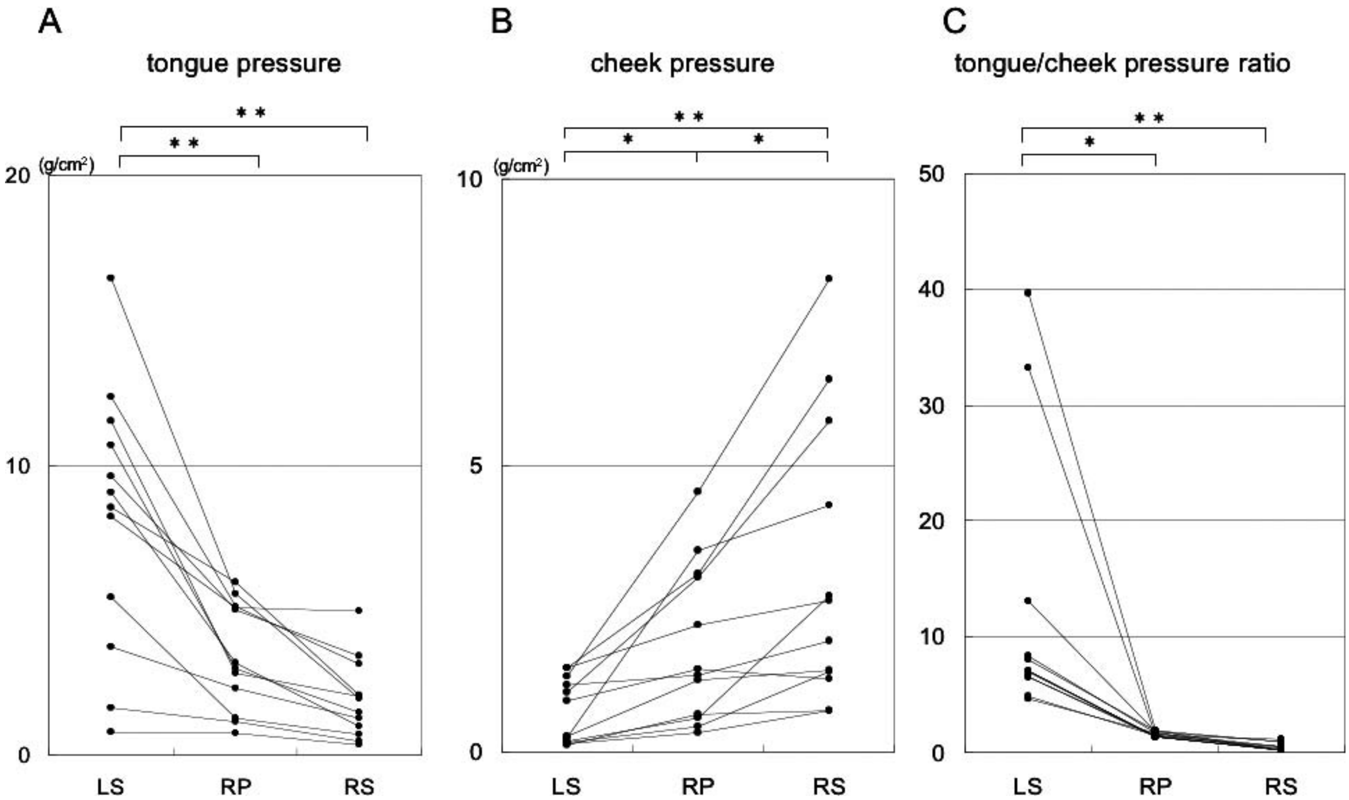

Figure 4. Comparison of the intraoral pressure among different mandibular positions in 12 subjects. (A) Tongue pressure. (B) Cheek pressure. (C) Tongue/cheek pressure ratio. * $P < .05$; ** $P < .01$. RP indicates rest position; RS, right-shifted position; LS, left-shifted position.

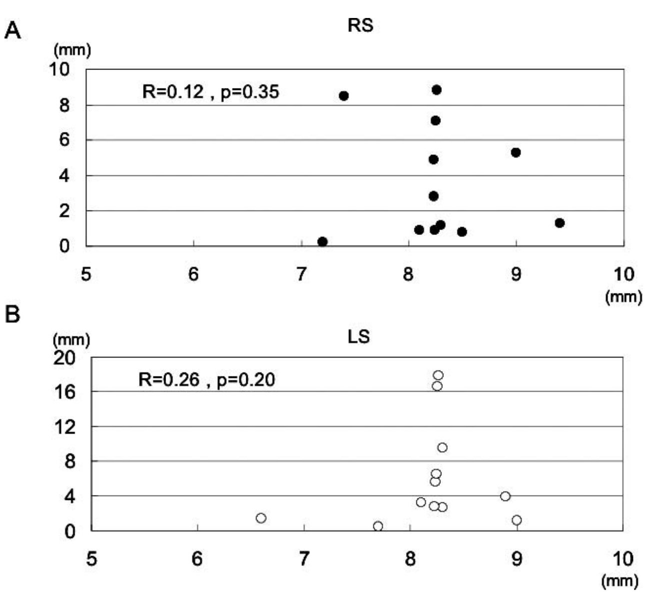

Figure 5. Relationship between displacement of the mandible (x-axis) and that of the tip of the tongue (y-axis). (A) Displacement to the right. (B) Displacement to the left. RS indicates right-shifted position; LS, left-shifted position.

Effect of Changes in the Breathing Mode and Body Position on Buccolingual Pressures

Takahashi and co-workers[17] measured tongue pressure at the mandibular anterior teeth in the supine position and found a rhythmical fluctuation in association with respiration. However, such a rhythm was not found at the lingual side of the mandibular molar region in our study. This is not surprising considering that the upper airway is influenced by the body position. The genioglossus muscle, the dilator muscle of the upper airway, expands the anteroposterior dimension of the respiratory tract by contracting its fibers that originate from the mental spine and run into the body of the tongue as a fan. Since the sensor was installed on the lingual side of the mandibular molar region in this study, it is thought that respiratory-related rhythm was not recorded because back-and-forth pressure is not easily perceived in contrast to horizontal pressure.

Dental Arch Form, Features of Tooth Axes, and Buccolingual Pressure in Subjects With Facial Asymmetry

In subjects with facial asymmetry, Shigefuji and co-investigators[9] found that the buccolingual tooth axes of the shifted side in the maxillary and mandibular first

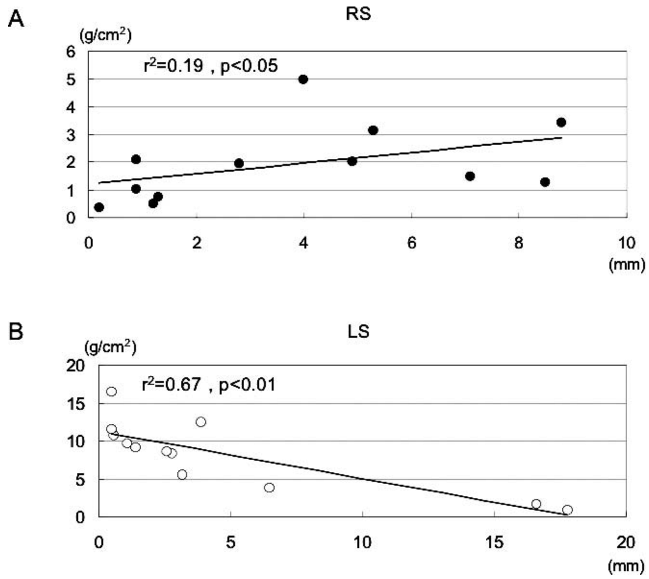

Figure 6. Relationship between displacement of the tip of the tongue (x-axis) and the tongue pressure (y-axis). (A) Displacement to the right. (B) Displacement to the left. RS indicates right-shifted position; LS, left-shifted position.

molars were significantly different from those of the nonshifted side. Moreover, Kusayama and colleagues[10] measured the distance from the midline to the second molars and the canines in the mandible of the shifted and nonshifted sides, and found asymmetry. They also reported a significant difference in lateral overjet between the shifted and nonshifted sides.[10] Suda and co-workers[11] reported a significant correlation between the buccolingual tooth axis of the mandibular molars on the shifted side and the amount of mandibular deviation. Thus, previous studies in subjects with facial asymmetry have suggested the possibility of dental compensation in the frontal plane in response to skeletal disharmony.

Based on the findings of this study, there were significant differences between LS and RP ($P < .05$) and LS and RS ($P < .01$) in the tongue/cheek pressure ratio. This indicates that an imbalance occurs between the tongue and cheek pressures when the mandible is shifted laterally, and suggests that this could affect the mandibular dental arch in subjects with facial asymmetry. The present results suggest that the tongue does not move in proportion to the mandibular deviation. Thus, even if the mandible moves, the tongue stays in its former position. Moreover, the less the tongue moves, the greater the effect of tongue pressure upon mandibular deviation. However, there are believed to be many complex pressures exerted on the dental arch during rest, chewing, swallowing, and pronunciation. Moreover, many factors such as habits, state of dental occlusion, and head posture have differential effects on the dental arch. However, the characteristics of buccolingual pressures in the resting position in subjects with facial asymmetry are still unclear. Considering these many factors, further studies are needed to reveal the mechanism that involves tongue pressure and lip pressure (cheek pressure) in an asymmetrical dental arch with dental compensation in subjects with facial asymmetry.

CONCLUSIONS

- When subjects without facial asymmetry experimentally shifted the mandible laterally, tongue pressure decreases on the shifted side, whereas it increases on the nonshifted side.
- Cheek pressure increases on the shifted side, whereas it decreases on the nonshifted side.

ACKNOWLEDGMENTS

The authors thank all of the volunteers who participated in the study. This study was supported by a Grant-in-Aid for Scientific Research Project (18390553) from the Japan Society for the Promotion of Science.

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