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Association between intraoral pressure and molar position and inclination in subjects with facial asymmetry

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SUMMARY Although it has been suggested that an imbalance in buccolingual pressure may play a role in dental compensation of the molars and asymmetry in the mandibular dental arch in subjects with facial asymmetry, it is still unclear whether buccolingual pressure is associated with this phenomenon. Thus, the purpose of this study was to test the null hypothesis that there are no differences in cheek and tongue pressure between the shifted and non-shifted sides in 12 (8 females and 4 males, mean age: 24.9 years) subjects with facial asymmetry defined as 4 mm or more deviation of the midline in the mandibular incisors. The resting buccolingual pressure on the bilateral mandibular first molars was measured simultaneously using four miniature pressure sensors. Moreover, a postero-anterior (PA) cephalogram was used to determine the buccolingual positions and the inclination of the mandibular first molars. Wilcoxon *t*-, Kruskal–Wallis *H*-, and Mann–Whitney *U*-tests and Spearman correlation coefficient by rank were used for statistical analysis. Significance was set at $P < 0.05$.

Cheek pressure was significantly greater on the shifted than that on the non-shifted side, while tongue pressure on the shifted side was significantly less than that on the non-shifted side. On the other hand, tongue/cheek pressure ratio on the shifted side was significantly less than that on the non-shifted side. There were significant differences between the shifted and non-shifted sides in the buccolingual positions and inclination of the mandibular first molars. Regardless of the side, there were significant negative correlations between the buccolingual position of the mandibular first molars and cheek pressure and significant positive correlations between the buccolingual position of the mandibular first molars and tongue/cheek pressure ratio. There were also significant negative correlations between tongue/cheek pressure ratio and inclination of the mandibular first molars on both the shifted and the non-shifted sides. Thus, the present findings reject the null hypothesis. The imbalance in buccolingual pressure in subjects with facial asymmetry appears to be related to dental compensation of the molars and mandibular asymmetry.

Introduction

Craniofacial morphology is a consequence of the interaction between genomic regulation and epigenetic modification involving anatomical and functional units (Moss, 1997a,b). The positions of the teeth and the form of the dental arch are subject to unremitting pressures from a circumoral muscular sling known as the 'buccinator mechanism' (Perkins *et al.*, 1977) and the tongue. Weinstein *et al.* (1963) measured intraoral pressure by installing a sensor in the region of the maxillary incisor, second premolar, and first molar. They found that the pressure from the tongue and lips was balanced and proposed the so-called 'equilibrium theory'. Proffit (1978) re-examined the equilibrium theory in the guinea pig and found that pressure from the periodontal membrane as well as from the tongue and cheeks played an important role. Research on equilibrium has continued (Fröhlich *et al.*, 1991, 1992), and a study that used simultaneous recording of cheek and tongue pressure in the molar regions found no significant differences between these pressures (Thüer *et al.*, 1999).

Craniofacial morphology is closely related to intraoral pressure. Proffit *et al.* (1975) investigated the craniofacial characteristics of Australian Aborigines and reported that they had bialveolar protrusion with flaccid lips. By comparing buccolingual pressures between Australian Aborigines and North Americans, they found that the lingual pressure in Australian Aborigines was less than that in North Americans in the mandibular incisor, canine, and molar regions, whereas lip pressure in Australian Aborigines was less in the incisor region. They also pointed out that resting intraoral pressure was more important than that during function in this interracial examination. Archer and Vig (1985) compared intraoral pressure at the mandibular incisor and molar regions in healthy subjects with Angle Class I and Angle Class II molar relationships in different head positions, natural, extended, and flexed. They found that in the natural head position, the tongue pressure in the mandibular molar region in Angle Class II subjects was less than that in Angle Class I subjects. They attributed this finding to the fact that Class II subjects had a retruded mandible and an extended head position.

With regard to the relationship between morphological characteristics and intraoral pressure, it has been reported that lip pressure in the maxillary incisor region in subjects with an Angle Class II division 2 malocclusion was greater than that in those with a Class I malocclusion, and there was a significant correlation between overbite and lip pressure (Lapatki *et al.*, 2002). Thus, most previous studies have investigated the relationship between intraoral pressure and craniofacial morphology in the sagittal dimension but not in the coronal/horizontal dimensions.

The aim of the present study was to investigate the relationship between intraoral pressure and compensatory features in the mandibular molar region in subjects with facial asymmetry. Thus, the null hypothesis that, in the molar region of subjects with facial asymmetry, there are no differences in buccal and lingual pressures between the shifted and non-shifted sides was tested. Moreover, whether the buccolingual position and inclination of the bilateral mandibular molars showed dental compensation was investigated.

Subjects and methods

Subjects

Twelve (8 females and 4 males) adult Japanese subjects with facial asymmetry, aged 24.9 ± 7.9 [mean ± standard deviation (SD)] years, participated after giving fully informed consent as provided in the protocol approved by the institutional ethics committee (approval #268). Subjects with a unilateral crossbite in the molar region were recruited. They had a full permanent dentition except for the third molars and without any oral habit. Facial asymmetry was defined as 4 mm or more deviation of the midline of the mandibular incisors to the cranial midline on a postero-anterior (PA) cephalogram. The subjects had not undergone previous orthodontic treatment. Both the lower incisor (5.1 ± 3.5 mm) and the menton (6.7 ± 4.4 mm) were deviated when compared with Japanese standards (Kato *et al.*, 1994; 0.6 ± 2.0 and 2.2 ± 1.7 mm, respectively). Subjects with congenital malformations, including clefting and temporomandibular joint dysfunction, and those who were taking any medication known to affect muscle activity or who had undergone orthodontic treatment were excluded from the study.

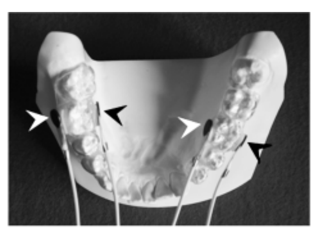
Recording of intraoral pressure

As described in previous studies (Narita *et al.*, 2002; Takada *et al.*, 2008), tongue and cheek pressure on the lingual and buccal surfaces of the bilateral mandibular first molar were simultaneously measured with two pairs of pressure sensors (PS-05KC; Kyowa Co., Tokyo, Japan) incorporated in the buccolingual plates of a custom-made intraoral appliance (Figure 1). Therefore, the four pressure sensors in the appliance were able to 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. Four cables led from the extraoral measuring system through the right oral rim to the pressure sensors, which allowed the plastic plate to be very thin with only minimal disturbance of the cheeks and tongue. The appliance was made using 0.75 mm thick plastic (Imprelon S; Scheu-Dental Co., Iserlohn, Germany). The sensitivity of the sensor was calibrated before and after each experimental session. Pressure was measured at a sampling frequency of 100 Hz (Takada *et al.*, 2008) and the acquired data were recorded with a personal computer by a warp measuring instrument (PCD-300A; Kyowa Co.) and analysed.

The subjects sat in a dental chair in the natural head position while breathing through their nose. After appliance insertion, a period of at least 5 minutes was allowed for habituation. 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 in the mandibular rest position at a sampling frequency of 100 Hz. Intraoral pressure was recorded five times. Five seconds were extracted at random from when the record from the pressure sensors was steady, and the mean and standard deviation (SD) of the intraoral pressure were calculated.

Cephalometric analysis

A PA cephalogram in the intercuspal position of each subject was taken to examine the buccolingual position and inclination of the mandibular first molars (Figure 2). The landmarks and contours used in the cephalometric analysis were defined using the method of Kecik *et al.* (2007).



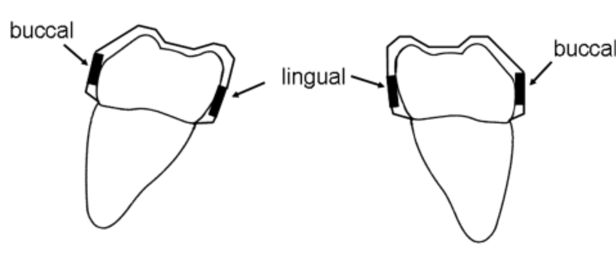


Figure 1 Pressure sensors in the intraoral appliance.

Statistical analysis

A Wilcoxon *t*-test ($P < 0.05$) was used to determine whether there were significant differences in the mean intraoral pressure and the relative ratio of tongue to cheek pressure in subjects with facial asymmetry. Kruskal–Wallis *H*- and Mann–Whitney *U*-tests ($P < 0.05$ with the Bonferroni correction) were used to determine whether there were significant differences between the tongue/cheek pressure ratio in subjects with facial asymmetry and in the rest position in healthy subjects as reported in a previous study (Takada *et al.*, 2008). Those authors investigated 12 healthy subjects without malocclusions (mean age: 28 years). 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. All subjects had a complete dentition with the exception of the third molars. Each subject had a normal overjet and overbite. A Wilcoxon *t*-test ($P < 0.05$) was also used to determine whether there were significant differences in the buccolingual positions and the inclination of the mandibular first molars between the shifted and non-shifted sides. A Spearman correlation coefficient by rank ($P < 0.05$) was used to evaluate the relationships between intraoral pressure and the buccolingual position and inclination of the mandibular first molars. All procedures were performed with the Statistical Package for Social Sciences (Release 10.0; SPSS Inc., Chicago, Illinois, USA).

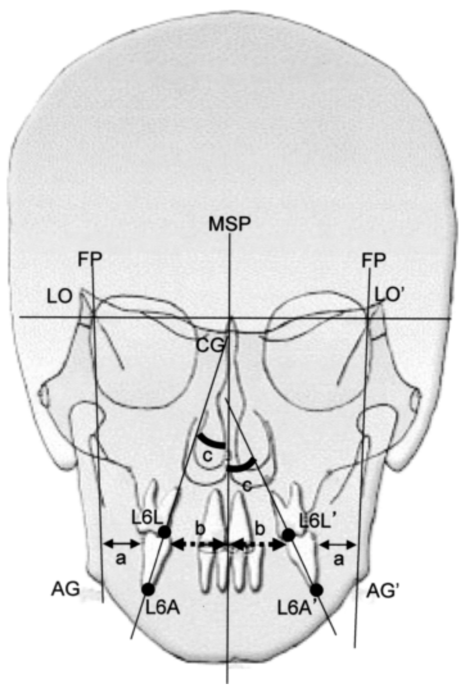


Figure 2 Landmarks and angular measurements in the cephalometric analysis (Kecik *et al.*, 2007). LO (LO′), intersection of the zygomaticofrontal suture with the orbita; AG (AG′), lateral and inferior point of the antegonial protuberentia; CG, neck of the crista galii; LO–AG (LO′–AG′), facial plane (FP); MSP, line perpendicular to the LO–LO′ a line passing through CG; L6L (L6L′), lingual cusp tip of the mandibular first molar; L6A (L6A′), lingual root apex of the mandibular first molar; a, distance between the buccal surface of the mandibular first molar and FP (L6b-FP); b, distance between the lingual surface of the mandibular first molar and MSP (L6l-MSP); c, the angle formed by MSP and the line connecting L6L (L6L′) and L6A (L6A′) (L6inc).

Results

Individual intraoral pressure

Individual tongue and cheek pressure in the rest position in the 12 subjects is shown in Figure 3. Cheek and tongue pressure on the shifted side was always greater than that on the non-shifted side in all subjects. Intraoral pressures are summarized in Figure 4. On the shifted side, cheek pressure was 5.78 ± 4.96 (mean ± SD) g/cm^2, while tongue pressure was 1.46 ± 1.39 g/cm^2. On the non-shifted side, cheek pressure was 2.58 ± 2.20 g/cm^2 and tongue pressure was 5.47 ± 3.34 g/cm^2. Thus, cheek pressure on the shifted side was significantly ($P < 0.05$) greater than that on the non-shifted side, while tongue pressure on the shifted side was significantly ($P < 0.05$) less than that on the non-shifted side. As a result, the molar on the shifted side was more inclined than that on the non-shifted side.

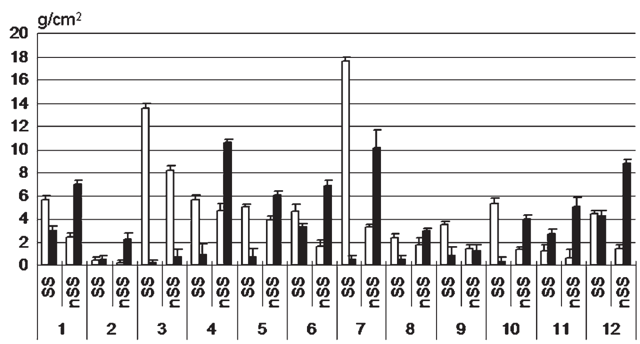


Figure 3 Individual intraoral pressures on the shifted (SS) and non-shifted (nSS) sides ($n = 12$). Open and solid bars indicate cheek and tongue pressure (g/cm^2), respectively.

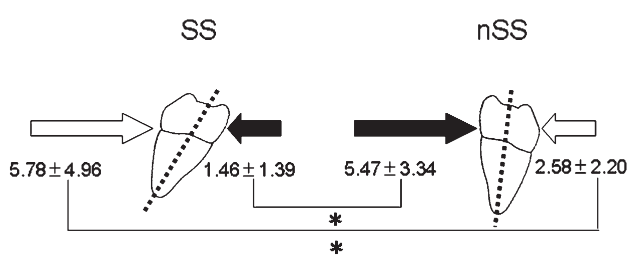


Figure 4 Means and standard deviations of intraoral pressures ($n = 12$). The molar on the shifted side (SS) is more inclined than that on the non-shifted (nSS) side. Open and solid arrows indicate cheek and tongue pressure (g/cm^2), respectively. *$P < 0.05$.

Comparison of tongue/cheek pressure ratio between subjects with and without facial asymmetry

Tongue/cheek pressure ratio on the shifted side was significantly less than that on the non-shifted side in subjects with facial asymmetry (Table 1). The data obtained in the present research were compared with that from the study of Takada *et al.* (2008). There were significant ($P < 0.05$) differences between the tongue/cheek pressure ratio on the shifted side in subjects with facial asymmetry than that on the experimentally shifted side in healthy controls. However, there were no significant differences between tongue/cheek pressure ratio on the non-shifted side in subjects with facial asymmetry and that on the experimentally shifted side in the healthy controls.

Comparison of buccolingual positions and inclination of the mandibular first molars

There were significant differences in the buccolingual positions and inclination of the mandibular first molars between the shifted and non-shifted sides in subjects with facial asymmetry (Figure 5). L6b-FP was significantly smaller and L6l-MSP significantly larger on the shifted side than that on the non-shifted side. L6inc was significantly larger on the shifted side than that on the non-shifted side.

Table 1 Comparison of tongue/cheek pressure ratio.

Subjects	Side	Mean ± standard deviation (g/cm^2)
Facial asymmetry	Shifted	0.31 ± 0.3
	Non-shifted	2.91 ± 2.2$^{\#}$
Control*		1.56 ± 0.2$^{\$}$

*From the study of Takada *et al.* (2008).
$^{\#}$ $P < 0.05$ between shifted and non-shifted sides in subjects with facial asymmetry, $^{\$}P < 0.05$ between control subjects and shifted side in subjects with facial asymmetry.

Relationship between buccolingual position and inclination of the mandibular molars and intraoral pressure

Regardless of the side, there were significant ($P = 0.021$ sifted side; $P = 0.001$ non-shifted side) negative correlations between L6b-FP and cheek pressure (Figure 6A). This suggests that as the distance from the first mandibular molars to the facial plane (FP) increases, the pressure exerted on the buccal surface of the mandibular molars decreases. There were no significant correlations between L6l-MSP and tongue pressure regardless of the side (Figure 6B). There were significant positive correlations between L6b-FP and tongue/cheek pressure ratio on both the shifted ($P = 0.040$) and the non-shifted ($P = 0.041$) sides (Figure 6C). This suggests that as the distance from the first mandibular molars to the FP increases, the pressure exerted on the buccal surface of the mandibular molars decreases. This, in turn, increases the tongue/cheek pressure ratio.

There was a significant ($P = 0.016$) negative correlation between tongue/cheek pressure ratio and L6inc on the shifted side (Figure 7). This indicates that as tongue/cheek pressure ratio increases either tongue pressure increases or cheek pressure decreases, or there is a combination of both. In any event, the mandibular molar uprighted, resulting in a reduction of buccolingual inclination. Likewise, there was a significant ($P = 0.034$) negative correlation between tongue/cheek pressure ratio and L6inc on the non-shifted side.

Discussion

Effects of body position and breathing mode on intraoral pressure

Archer and Vig (1985) measured intraoral pressure in subjects with different Angle classifications in the natural, extended, and flexed head positions. The resting lip and tongue pressure showed different values in all head positions. Thus, head position was set in the present study in the natural position to avoid the effect of head position on

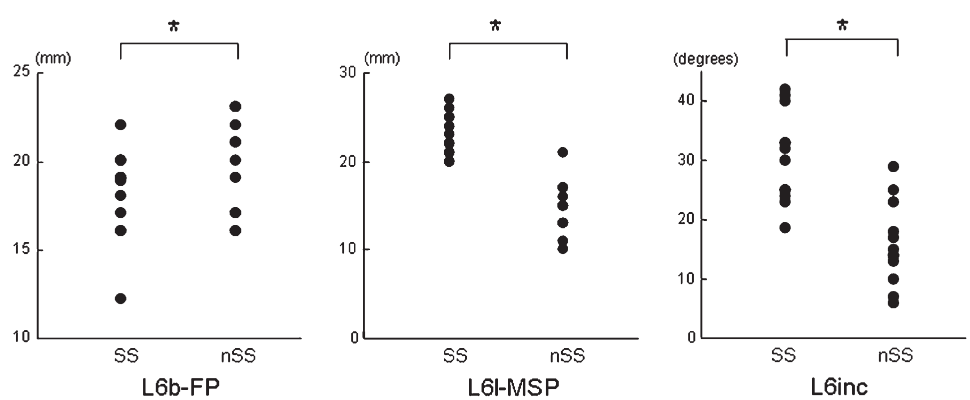


Figure 5 Comparison of buccolingual positions and inclination of the mandibular first molars on the sifted (SS) and non-shifted (nSS) sides ($n = 12$). $*P < 0.05$. L6b–FP, distance between the buccal surface of the mandibular first molar and FP; L6l–MSP, distance between the lingual surface of the mandibular first molar and MSP; L6inc, the angle formed by MSP and the line connecting L6L (L6L′) and L6A (L6A′).

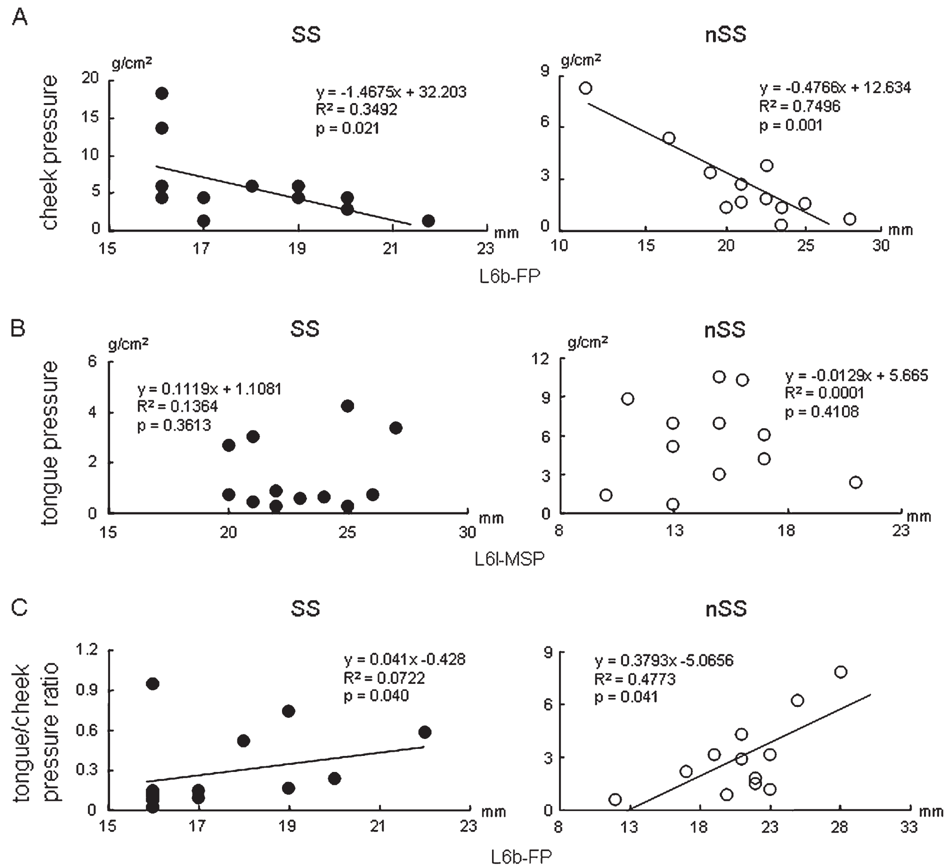


Figure 6 Relationships between the buccolingual position of the first mandibular molars and intraoral pressure on the shifted (SS) and non-shifted (Nss) SIDES (n = 12). (A) Relationship between the distance from the buccal surface of the mandibular first molar (L6b) and facial plane (FP) and cheek pressure; (B) between the distance from the lingual surface of the mandibular first molar (L6l) and MSP and tongue pressure; (C) between the distance from L6b–FP and the tongue/cheek pressure ratio. Abbreviations: SS, shifted side; nSS, non-shifted side.

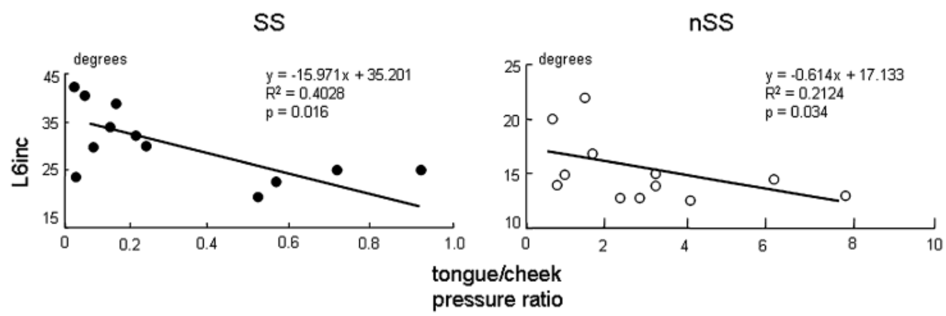


Figure 7 Relationships between the inclination of the first mandibular molars (L6inc) and tongue/cheek pressure ratio (n = 12).

intraoral pressure. The breathing mode is known to influence intraoral pressure via extrinsic tongue muscle activity (Takahashi *et al.*, 1999, 2002). Takahashi *et al.* (1999) reported that maximum tongue pressure during oral breathing was significantly greater than during nasal breathing in both the upright and the supine positions. Moreover, there seemed to be less variability in intraoral pressure during nasal than oral breathing in both the upright and supine positions. Therefore, the subjects in the study were asked to breathe through the nose during the experimental session.

Relationship between buccolingual position, inclination of the mandibular molars, and intraoral pressure

Several studies have observed asymmetry in the shape of the mandibular dental arch and molar inclination in subjects with facial asymmetry, which was considered to be a compensatory response (Shigefuji *et al.*, 2001; Suda *et al.*, 2001; Kusayama *et al.*, 2003). Shigefuji *et al.* (2001) found that the bucco-lingual tooth axes of the maxillary and mandibular first molars on the shifted side were significantly different from those on the non-shifted side in subjects with facial asymmetry. A significant correlation has been reported between the buccolingual inclination of the maxillary (Shigefuji *et al.*, 2001) and mandibular (Suda *et al.*, 2001) first molars and the amount of mandibular deviation. Kusayama *et al.* (2003) also found significant differences in the buccolingual tooth axes of the maxillary and mandibular molars between the shifted and non-shifted sides in subjects with facial asymmetry. They also observed significant differences in the occlusal cant and curve of Spee between the shifted and non-shifted sides. These findings suggest that the existence of dental compensation in the FP is a response to skeletal deformity.

Shigefuji *et al.* (2001), Suda *et al.* (2001), and Kusayama *et al.* (2003) explored the anatomical (i.e. static) features in the coronal dimension in subjects with facial asymmetry; however, it is still unclear whether functional (i.e. dynamic) factors are involved in these phenomena. Thus, a preliminary investigation was undertaken in order to determine if there was an imbalance between buccal and lingual pressures in the experimentally shifted mandible in subjects without facial asymmetry (Takada *et al.*, 2008). In that study, the buccal pressure in the molar region was greatest when the mandible was shifted ipsilaterally to the recording side, decreased in the resting position, and smallest when the mandible was shifted contralaterally to the recording side. In contrast, lingual pressure in the molar region was smallest when the mandible was shifted ipsilaterally to the recording side, increased in the resting position, and greatest when the mandible was shifted contralaterally to the recording side. Therefore, it was suggested that there was a close relationship between mandibular shift and intraoral pressure (Takada *et al.*, 2008). The imbalance in buccolingual pressures in the laterally shifted mandible in healthy subjects may partly explain mandibular molar dental compensation and asymmetry of the dental arch in subjects with facial asymmetry. However, it was unclear whether a change in buccolingual pressure also occurs in subjects with facial asymmetry.

In the present study, buccal pressure increased as the mandibular molars were displaced buccally regardless of the side of the shift (Figure 6A). On the other hand, there was no similar linear relationship between lingual pressure and lingual displacement of the mandibular molar (Figure 6B). This may indicate that the buccinator mechanism, rather than the tongue, exerts more effective pressure on the buccolingual positioning of the mandibular molars. Moreover, the significant relationship between buccal displacement of the mandibular molars and buccal pressure seemed to strongly influence the marginally significant relationship between buccal displacement of the mandibular molars and the tongue/cheek pressure ratio (Figure 6C). Although there was no significant relationship between lingual pressure and lingual displacement of the mandibular molar, the combination of buccal and lingual pressure was significantly correlated with buccolingual inclination of the mandibular molar (Figure 7).

Comparison of intraoral pressure between subjects with and without facial asymmetry

A recent study compared occlusal pressure, contact area, and force between subjects with and without facial asymmetry (Goto *et al.*, 2008). The occlusal pressure on the non-shifted side in subjects with facial asymmetry was significantly greater than in those without facial asymmetry. In addition, the occlusal contact area and the occlusal force on the shifted side were larger than that on the non-shifted side in subjects with facial asymmetry. The values in subjects with facial asymmetry were significantly smaller than in those without facial asymmetry (Goto *et al.*, 2008). Therefore, there may be some disharmony between the shifted and non-shifted sides in subjects with facial asymmetry, as well as between subjects with and without facial asymmetry. This is in accord with the comparative difference in the tongue/cheek pressure ratio between the shifted and non-shifted sides in subjects with facial asymmetry, as well as between subjects with and without facial asymmetry (Table 1).

Intraoral pressure and molar position and inclination

Intraoral pressure in the rest position has been considered more important for the position of the teeth than that during function, including swallowing and chewing, based on the difference of duration in a day (Proffit, 1978). Fröhlich *et al.* (1993) performed a longitudinal study of the effect of surgical tongue reduction on lingual pressure on the teeth. Six months after surgery, the lingual pressure at rest showed a significant reduction compared with that before surgery in the mandibular molar region. The lingual pressure at rest recovered to the pre-surgical value 12 months after surgery. On the other hand, both the lingual pressures during chewing and swallowing in the mandibular molar region showed no significant difference pre- and post-surgery. It was thus assumed during the short period after surgery the mandibular molars may tend to incline lingually, if the lingual pressure at rest is more important than that during function.

However, it is believed that many complex pressures are exerted on the dental arch during rest, chewing, swallowing, and speech. Factors such as oral habits, occlusal condition, and head posture have differential effects on the dental arch. Considering these factors, further studies with more subjects will be needed to reveal the mechanism that involves tongue pressure and lip/cheek pressure in an asymmetric dental arch with dental compensation in subjects with facial asymmetry. A longitudinal study with a large sample size to follow changes in buccolingual pressure in subjects with facial asymmetry before and after orthognathic treatment may help to clarify the cause–effect relationship between morphological and functional asymmetry in subjects with facial asymmetry.

Conclusions

The findings of this study showed that there was a significant difference in tongue/cheek pressure ratio between the shifted and non-shifted sides in subjects with facial asymmetry. In addition, there were significant differences between the shifted and non-shifted sides in the buccolingual positions and inclination of the mandibular molars. There were significant positive correlations between tongue/cheek pressure ratio and buccolingual position and inclination of the mandibular first molars. The results suggest that the imbalance in intraoral pressure may be related to dental compensation of the molars and asymmetry in the mandibular arch in subjects with facial asymmetry.

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