*Original Article*

# Interaction between deglutition, tongue posture, and malocclusion: *A comparison of intraoral compartment formation in subjects with neutral occlusion or different types of malocclusion*

**Michael Knösel[a]; Carolin Nüser[b]; Klaus Jung[c]; Hans-Joachim Helms[d]; Wilfried Engelke[e]; Paulo Sandoval[f]**

## ABSTRACT

**Objective:** To test the null hypothesis of no significant difference in terms of intraoral pressure curve characteristics assessed simultaneously at the subpalatal space (SPS) and the vestibular space (VS), during different oral postures, between four groups with either an Angle Class II/1 (II1), Angle Class II/2 (II2), anterior open bite (O) malocclusion, or a neutral occlusion control group (I).

**Materials and Methods:** Intraoral pressure recordings were performed simultaneously in the VS and SPS of 69 consecutive subjects ($n_{II1} = 15$; $n_{II2} = 17$; $n_O = 17$; $n_I = 20$; mean age/standard deviation 18.43/6.60 years). Assessments included defined sections of open mouth posture (OMP, 30 seconds), anteriorly closed mouth condition (60 seconds), dynamics by a tongue-repositioning maneuver (TRM, 60 seconds), swallowing, and positive pressure generation (PP, 10 seconds). Interactions of malocclusion, compartment location, and posture on pressure curve characteristics were analyzed by Kruskal-Wallis and Mann-Whitney *U*-tests, adopting an $\alpha$ level of 5%.

**Results:** Globally significant group differences were detected at the VS (plateau duration and median peak heights during TRM; area under pressure curve [AUC] during PP) and SPS (AUC during TRM and PP). Subjects with anteriorly nonopen dental configurations (groups I and II2) were able to keep negative pressure levels at the VS for longer time periods during TRM, compared to groups O and II1.

**Conclusions:** The null hypothesis was rejected for mean VS plateau durations and peak heights and for SPS AUC. Negative pressures at the VS may stabilize outer soft tissues passively and may explain the dental arch form shaping effect by mimic muscles. (*Angle Orthod.* 2016;86:697–705.)

**KEY WORDS:** Tongue posture; Deglutition; Norm-occlusion; Malocclusion; Intraoral pressure; Oral posture

[a] Professor, Department of Orthodontics, University Medical Center Göttingen, Göttingen, and Private Practice, Hamburg, Germany; and Visiting Professor, Department of Orthodontics, Universidad de La Frontera, Temuco, Chile.

[b] Research Fellow, Dentist, Private Practice, Itzehoe, Germany.

[c] Biostatistician, Professor, Department of Medical Statistics, University Medical Center Göttingen, Göttingen, Germany; and Institute for Animal Breeding and Genetics, University of Veterinary Medicine Hannover, Hannover, Germany.

[d] Biostatistician, Research Assistant, Department of Medical Statistics, University Medical Center Göttingen, Göttingen, Germany.

[e] Professor, Department of Maxillofacial Surgery, Universidad de La Frontera, Temuco, Chile.

[f] Professor, Department of Paediatrics and Orthodontics, Universidad de La Frontera, Temuco, Chile.

Corresponding author: Professor Dr Michael Knösel, Lübecker Str. 128, 22087 Hamburg, Germany
(e-mail: mknoesel@yahoo.de)

## INTRODUCTION

The cause of malocclusion is widely accepted to be multifactorial and includes genetic factors as well as habits, dietary preferences, habitual oral or tongue posture, and swallowing characteristics.[1–4] While most of the theories accept genetics as the main or underlying cause, the importance of local or environmental factors, such as oral posture and oral soft tissue characteristics, is also widely accepted, as these factors can have both a deteriorating and enhancing influence. The fact that muscle weakness

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is connected with the increase of vertical growth is generally agreed upon.[4] In addition, patients with habitual open mouth posture were identified as having a significantly reduced growth of the maxillary arch.[5] The detrimental influence of deviating tongue posture on the formation of malocclusion has been underlined by Harvold et al.,[6] who displaced the tongue of rhesus monkeys from its normal posture and subsequently recognized extensive occlusal and skeletal changes. Another study[7] in children with unilateral posterior crossbite also showed, using a three-dimensional ultrasound, that tongue posture is an important factor in the development of malocclusions. However, evidence that tongue dynamics and resting postures are functional factors is still scarce, as it is difficult to achieve real-time parameterization of intraoral soft tissues.[4] Approaches involving the use of magnetic resonance imaging, or even radiographic methods, involve ethical issues.[8]

A noninvasive method of assessing tongue posture during function is the use of the intraoral manometry technique.[9–12] This technique is based on the concept of the biofunctional model of the oral cavity, combining aspects from anatomy, dentistry, and otorhinolaryngology.[13] It describes biofunctional compartments or spaces that typically form during deglutition, speech, and at respiratory resting posture in norm-occlusion subjects: These are the vestibular space (VS) and the subpalatal space (SPS).[14] The first space (VS) is limited by the cheeks, lips, and the lateral and base of the tongue and is defined as the space surrounding the dental arches. The latter space (SPS) is limited by the dorsum of the tongue and the center of the hard palate. Formation of negative pressure at the SPS as well as differentiation of the two functional intraoral soft tissue compartments have been reported[11,13] to be a prerequisite for the initiation of the physiological act of deglutation. The type of swallowing has been shown[1–4] to have an impact on normal or deviating occlusal and dentofacial development.

In order to achieve a deeper understanding of orofacial biofunctions and to better explain previously detected significant interactions between deglutition, oral posture, and malocclusions, the aim of the present study was to assess the intraoral pressure curve characteristics at the VS and SPS of groups of subjects with different occlusal traits (neutral occlusion, Angle Class II/1, Angle Class II/2, and open bite malocclusion), at rest and during different oral postures and functional maneuvers. We tested the null hypothesis that there is no significant difference in terms of pressure curve characteristics at the VS and SPS during functioning between them.

## MATERIALS AND METHODS

### Subjects

The study received the full approval of the local ethics committee (No. 27/7/09). Sixty-nine subjects (male/female = 29/40; mean age/standard deviation [SD] = 18.43/6.60 years; Table 1) were consecutively recruited by one assessor at two centers (University of Göttingen, Germany; Private Practice, Itzehoe, Germany), according to the inclusion and exclusion criteria presented in Table 1.

Within the time period of July 1, 2009, to October 31, 2012, initial diagnostic plaster casts of all new patients were screened. Based on their occlusal traits, subjects were assigned to one of four malocclusion groups. The definitions and compositions of those groups are provided in Table 1, as follows: group I, norm-occlusion subjects; groups II1 and II2, subjects characterized by an Angle Class II/1 or II/2 malocclusion and clinically proclined (II1) or reclined incisors (II2); and group O, subjects characterized by an anterior open bite of least of 1 mm.

### Materials and Methods

Recordings of different pressures at the interocclusal or VS and at the SPS were performed chairside, with the head in the natural position, by a single operator (C.N.). A digital precision pressure meter (GMH3156; with two piezo-resistant relative pressure sensors GMSD350MR; measuring range/resolution 500/0.1 mbar (rel); software: GSOFT3050; Greisinger, Regenstauf, Germany) was connected by flexible polyvinyl chloride tubes (4-mm inside diameter) to the VS and SPS. A thin flexible cap of a venous catheter (Braun, Melsungen, Germany) served as the end piece at the SPS; it was threaded through the dental arches. A dental suctor's end cap was attached to the VS tube and placed lateral to the premolar region (VS) in order to avoid blocking by soft tissues (Figure 1).

### Definition of Oral Postures During Recordings

Measurements were repeated three times with each participant. Each pressure recording cycle lasted for 3 minutes and was divided into six sections or stages: Participants were instructed to perform different maneuvers or to adopt defined oral postures (Table 2). Each participant was carefully instructed and trained prior to initiations of the recordings.

### Statistical Analysis

The first and the last 5 seconds of each assessment interval were cut in order to receive measurements at

**Table 1.** Definition of Inclusion Criteria, Subject and Group Characteristics, and Numbers of Included and Excluded Subjects, With Reasons

| | Group | | | | |
|---|---|---|---|---|---|
| | I | II1 | II2 | O | All |
| General inclusion criteria | Absence of gaps in upper or lower dental arches<br>• Absence of common colds, cough, coryza, or any other health conditions that would affect or impede nasal respiration or mouth breathing<br>• Willingness and ability to comply with and follow instructions during pressure assessments<br>• Completed mixed dentition stage 1 (full eruption of all permanent incisors and first molars) or complete permanent dentition | | | | |
| General exclusion criteria | • Gaps within either of the dental arches (eg, by missing deciduous teeth)<br>• Orthodontic treatment history | | | | |
| Group-specific inclusion criteria | Norm-occlusion without side shift or crossbites and with vertically and sagittally well-supported incisors without major crowding >2 mm | Angle Class II malocclusion of least of ½ cusp of distal molar and canine relation and clinically proclined incisors | Angle Class II malocclusion of least of ½ cusp of distal molar and canine relation and clinically reclined incisors | Negative overbite (open bite) of least of −1 mm; | |
| Mean age, y (SD) [minimum; maximum] | 26.93 (7.51) [23.2; 57.8] | 11.41 (1.54) [8.1; 14.3] | 19.82 (9.55) [10.1; 35.5] | 15.56 (7.79) [8.4; 37.6] | 18.43 (6.60) [8.1; 57.8] |
| Potentially eligible subjects (n) | 20 | 19 | 19 | 21 | 79 |
| Excluded subjects (n), with reasons | 0 | Gaps in dental arch: n = 2 Unwilling to cooperate n = 2 | Gaps in dental arch: n = 2 | Gaps in dental arch: n = 4 | 10 |
| Included subjects (n) | 20 (males/females: n = 9/11) | 15 (males/females: n = 8/7) | 17 (males/females: n = 6/11) | 17 (males/females: n = 6/11) (Angle Class I: n = 5 Angle Class II: n = 11 Angle Class III: n = 1) | 69 (males/females: n = 29/40) |

rest. Different parameters were extracted from the recorded pressure curves in order to assess the influence of the factors of malocclusion (groups I, II1, II2, and O) and localization of intraoral compartment (VS, SPS) separated by six sections. These were the area under the curve (AUC), frequencies and median heights (mbar) of swallowing peaks (defined as a change of pressure of 5 or more mbar in less than 1 second and a second change [decrease] within 5 seconds), pressure plateaus of >5 seconds, and median plateau duration (seconds). Signal extraction was implemented using a methodology proposed previously.[14]

Extracted curve parameters of all malocclusion groups were globally compared by assessment section and compartment location using the Kruskal-Wallis test. In case of significant differences, pairwise comparisons of malocclusion groups and assessment sections were implemented, separately for the VS or SPS compartment, using Mann-Whitney *U*-tests. All analyses were performed using the software R (www.r-project.org), adopting an $\alpha$ level of.05.

## Method Error

Repeated intraoral pressure measurements have been reported[10,12,13,15] to be subject to variation. Therefore, intraoral measurements were repeated three times with each participant in order to test the robustness of the distinctive parameters. Repeated-measures analysis of variance was used per curve characteristic to evaluate whether there was a significant effect of the replicates or an individual × replicate interaction. No significant effects were detected by the measurement replicates ($P > .05$ for each curve characteristic). Therefore, the three replicates per individual were averaged prior to further analysis.

## RESULTS

Means and standard deviations of all extracted curve parameters are given separately for the VS and the SPS compartment measurements in Table 3. Subjects with anteriorly nonopen dental configurations (groups I and II2) were able to keep negative pressure levels at the VS for longer time periods during the tongue-repositioning maneuver (TRM), compared to

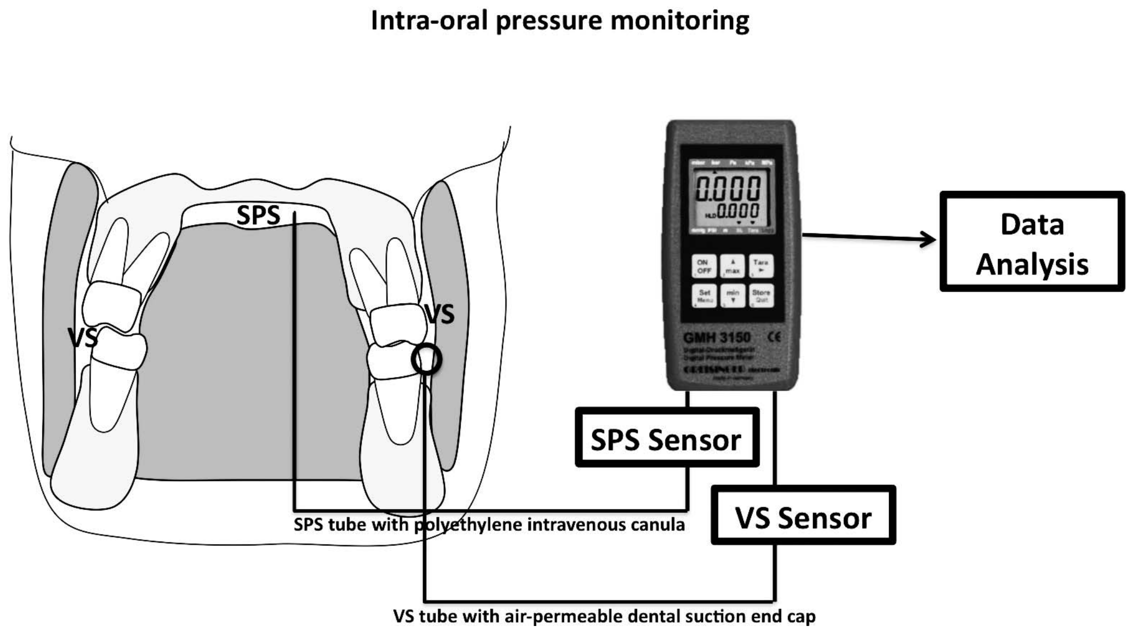


**Figure 1.** Schematic of the experimental setup.

groups O and II1. Global comparisons of all four malocclusion groups yielded the result of significant differences in terms of SPS vs plateau duration during TRM; these were due to differences between the subjects of groups I and II2 and those of group O (Tables 4 and 5). Table 6 depicts results of comparisons of VS and SPS measurements.

## DISCUSSION

Successful correction of malocclusion and long-term stability of achieved occlusions is widely accepted to be enhanced by the absence of oral dysfunction and postural habits, such as habitual open mouth postures, or swallowing patterns characterized by tongue thrust movements.[2,4,5,11,16] The objective of the present study was therefore to screen intraoral soft tissue dynamics and parameterize tongue posture during swallowing considered to be normal.[13] That is, in terms of the presence or absence of incisor contact during occlusion, two of the groups (II1 and O) were characterized by either a vertically or sagittally open incisor situation, while the two other groups (I and II2) were not. The null hypothesis that there is no significant difference in terms of intraoral pressure curve characteristics assessed at the VS and SPS during function between the groups with different occlusal traits was thus rejected for mean plateau durations assessed at the VS (groups I and II2 compared to group O) during section TRM (Table 3) and for AUC assessed at the SPS during TRM (Table 4; group I significantly increased compared to group II2 [Table 5]).

### Robustness of the Method

Some variation in repeated, intraindividual, intraoral pressure recordings has been previously reported by several groups.[10,12,13,15] Three-time repeated assessments yielded no significant intraindividual differences, and the replicates were

**Table 2.** Definition and Durations of Sections of Pressure Recordings

| Section No. | Description (Abbreviation) | Duration (s) | Instruction Given to Subjects During Recording |
|---|---|---|---|
| 1 | Open mouth condition (OMP) | 0–30 | To slightly open the lips and to breathe normally |
| 2 | Anteriorly closed condition (ACC) | 31–90 | To gently close their lips and to continue breathing normally |
| 3 | Tongue-repositioning maneuver (TRM)[13] | 91–150 | To collect saliva, then to swallow and to subsequently keep on breathing normally for 60 s |
| 4 | Swallowing (SW) | 151–155 | To swallow saliva and keep on breathing normally for another 5 s |
| 5 | Positive pressure condition (PP) | 156–160 | To create positive intraoral air pressure by inflating cheeks |
| 6 | Testing for saliva-blocked cannulas: relapse to environmental pressure? (T) | 161–165 | To remove intraoral cannulas/sensors; recordings proceeded for 5 s |

averaged for further analysis in order to improve the robustness of pressure parameters.

Furthermore, section T assessments were used as an additional control in terms of assessing potential blocking of the cannulae by saliva: There was a relapse to atmospheric ambient pressure following removal of the cannulae from the oral cavity (Table 3), indicating the presence of no or only few saliva, with no significant differences between the test groups and cannulae (Tables 4 and 5).

### Area Under the Curve

Considering the overall generated negative pressure, as represented by the AUC, a more negative pressure was noted for the SPS compared to the VS (Table 3). This feature applied to both norm-occlusion and malocclusion subjects and thereby partially confirms the outcome of a previous study[13] on intraoral compartment formation in norm-occlusal subjects.

The global comparison of the AUC values between the four study groups yielded significant differences for the positive pressure (PP) section, separately for compartments SPS and VS (Table 4). In both compartments, these global group differences were due to significant differences during PP between the subjects of groups I and II1 and those of the open bite group O (Tables 3 and 5). Also, AUC at the SPS was globally significant during section TRM (Table 4), and this was due to formation of significantly more negative SPS pressures in group I, compared to assessments in group II2 (Table 5).

### Frequencies of Peaks and Plateaus

Frequencies of peaks and plateaus and the median plateau duration can be considered representative features of intraoral soft tissue dynamics of the two functional compartments. However, we did not detect significant differences in the global comparison of measurements made at the cheek (VS) or at the SPS for frequencies of peaks or plateaus (Table 4). That is, quantities of swallowing activities are similar for subjects with norm-occlusion and malocclusion and do not seem to interact with presence of malocclusion.

### Median Peak Height

Global comparison of VS measurements yielded significant results for the TRM (Table 4). Further splitting by intergroup comparisons in section TRM yielded significant differences for group I (Figure 2) compared to group O and for group II1 compared to group O (Table 5). Average negative swallowing peaks at the VS were significantly higher in subjects of groups I and II1 ($-34.5$ to $-39.6$ mbar) compared to those of group O ($-24.4$ mbar; Table 5). Thus, median swallowing peak height is not seen as a feature that is clearly associated with the presence or absence of malocclusion. Comparing pressures levels in both compartments, median peak height was, in general, more negative at the SPS compared to the VS, with exceptions made for group I (sections open mouth condition [OMP] and anteriorly closed condition [ACC]) and group O (section OMP; Table 3). That is, in terms of quality of swallowing activities, the typical pattern of more negative pressures at the SPS seen in norm-occlusion subjects[13] is also seen in a majority of malocclusion subjects.

### Median Plateau Height and Duration

No significant differences were seen for global comparisons between median plateau heights at the VS or SPS of the various groups (Table 4). However, a global, separate consideration of VS pressures did yield significant differences in terms of median plateau duration yielded during section TRM (Table 4), and these were due to differences between norm-occlusion and open bite subjects and were also due (Figure 2) to those differences between group II2 and group O (Table 5). Mean VS plateau durations of groups I and II2 were distinctively longer (37.6–38.5 seconds) compared to those of group O (23.2 seconds), and, though not significant, were also longer in comparison to those of group II1 (25 seconds; Table 3). This seems to confirm the results of a previous study,[17] in which single measurements at the vestibule yielded the result of longer plateau durations for subjects with Angle Class II/2 malocclusion, compared to norm-occlusion subjects. The formation of negative pressures at the SPS has been shown earlier to be a prerequisite for the initiation of deglutition. Thus, we interpreted our findings to indicate that SPS negative pressures are comparable for the various groups with different occlusal traits and do not seem to be affected by the presence or absence of malocclusion. However, significant differences in terms of negative pressures assessed at the VS indicate a clear tendency that subjects with anteriorly nonopen dental configurations (groups I and II2), in contrast to vertically or sagittally open incisor configurations (as in groups O and II1) are able to keep negative pressure levels at the VS for longer time periods. These negative VS pressures are assumed to stabilize the soft tissues of the cheeks and lips physically and passively, especially during absence of neuromuscular activity. This type of passive stabilization may, in turn, contribute to the explanation of the dental arch form shaping effect of soft tissues.

**Table 3.** Mean ± Standard Deviation of Negative Pressure Characteristics, Separately for Section and Group, in the Measurements at the Vestibular Space (VS; Cheek) and Subpalatal Space (SPS). Duration of Stages 4, 5, and 6 (Swallowing [SW], Positive Pressure [PP], and Test Stage [T]) Did Not Allow for an Assessment of Peak and Plateau Features[a]

| | | Peaks (n) | | Median Peak Height (mbar) | | Plateau Frequencies (n) | |
|---|---|---|---|---|---|---|---|
| Section | Group | VS | SPS | VS | SPS | VS | SPS |
| OMP | I | 0.1 ± 0.2 | 0.2 ± 0.4 | 25.3 ± 23.9 | 16.3 ± 16.6 | 0 ± 0.1 | 0 ± 0 |
| OMP | II1 | 0.3 ± 0.4 | 0.3 ± 0.3 | 14.5 ± 10.6 | 20.6 ± 15.1 | 0 ± 0.2 | 0.1 ± 0.3 |
| OMP | II2 | 0.2 ± 0.3 | 0.3 ± 0.4 | 12.9 ± 9.8 | 39 ± 31.8 | 0 ± 0.1 | 0.2 ± 0.4 |
| OMP | O | 0.2 ± 0.4 | 0.3 ± 0.7 | 13.1 ± 4.1 | 12.9 ± 4.4 | 0 ± 0 | 0.1 ± 0.3 |
| ACC | I | 1 ± 0.7 | 1.1 ± 0.9 | 28.7 ± 20.9 | 25.8 ± 11.9 | 0.2 ± 0.4 | 0.1 ± 0.3 |
| ACC | II1 | 1.7 ± 1.1 | 1.8 ± 0.9 | 31.3 ± 14.4 | 37 ± 21.3 | 0.6 ± 0.7 | 0.6 ± 0.9 |
| ACC | II2 | 1.1 ± 1 | 1.2 ± 0.9 | 19.6 ± 8.8 | 28.4 ± 27.2 | 0.4 ± 0.8 | 0.5 ± 0.6 |
| ACC | O | 1 ± 0.9 | 1.3 ± 1 | 19.3 ± 13.5 | 35 ± 32.9 | 0.4 ± 0.8 | 0.6 ± 0.9 |
| TRM | I | 1.7 ± 0.6 | 1.8 ± 0.6 | 34.5 ± 23.3 | 50 ± 30.1 | 1 ± 0.6 | 1.3 ± 1 |
| TRM | II1 | 2 ± 1.1 | 2.1 ± 0.8 | 39.6 ± 22.6 | 46.2 ± 34.8 | 1.4 ± 1.2 | 1.3 ± 1.1 |
| TRM | II2 | 1.5 ± 1 | 1.6 ± 0.9 | 24.6 ± 17.5 | 32.2 ± 30.8 | 0.7 ± 0.9 | 0.8 ± 0.8 |
| TRM | O | 1.4 ± 0.8 | 1.6 ± 0.9 | 24.4 ± 25.5 | 40.2 ± 51.1 | 0.8 ± 0.9 | 1.1 ± 0.9 |
| SW | I | | | | | | |
| SW | II1 | | | | | | |
| SW | II2 | | | | | | |
| SW | O | | | | | | |
| PP | I | | | | | | |
| PP | II1 | | | | | | |
| PP | II2 | | | | | | |
| PP | O | | | | | | |
| T | I | | | | | | |
| T | II1 | | | | | | |
| T | II2 | | | | | | |
| T | O | | | | | | |

[a] OMP indicates open mouth condition; ACC, anteriorly closed condition; TRM, tongue-repositioning maneuver; O, anterior open bite occlusion; and I, neutral occlusion (control).

## Differentiation of Compartments VS and SPS

The use of two different end pieces for VS and SPS has been proved previously to not have an influence on enabling pressure measurements.[17] The diameter of the tube has no influence on assessed pressures and is owed instead to the anatomical situation (ie, prevention of blocking of soft tissues by the suctor end cap and small dimensions of the SPS canula to enable teeth contacts during measurements). In section OMP, all groups showed a differentiation of compartments, as evident by significant differences in the AUC assessed at the VS and SPS (Table 6). The negative pressure in the VS can be explained by subjects subconsciously sucking on the dental suctor cap, perhaps including some buccinator activity. In addition, norm-occlusion subjects showed a differentiation of compartments in section ACC, as evident by the significantly different VS SPS pressure plateau durations in contrast to those of subjects with any type of malocclusion.

## Limitations

The inclusion criterion of no orthodontic treatment history may have contributed to a decreased mean age of group II1 subjects, compared to those of the other groups. This was due to the difficulties in finding

**Table 4.** *P*-Values for the Global Comparison (All Four Malocclusion Groups), Separated by Section, in the Measurements at the Vestibular Space (VS) and Subpalatal Space (SPS). Bold Values Indicate Significance[a]

| | Peaks (n) | | Median Peak Height (mbar) | | Plateaus (n) | | Median Plateau Height (mbar) | | Duration of Plateaus (s) | | Area Under the Curve | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stage | VS | SPS | VS | SPS | VS | SPS | VS | SPS | VS | SPS | VS | SPS |
| OMP | .07 | .3 | .9 | .4 | .6 | .2 | .41 | .09 | .3 | .7 | .06 | .4 |
| ACC | .2 | .2 | .1 | .5 | .3 | .09 | .45 | .48 | .9 | .1 | .5 | .3 |
| TRM | .4 | .2 | **.045** | .1 | .1 | .3 | .77 | .058 | **.039** | .2 | .06 | **.049** |
| SW | | | | | | | | | | | .9 | .9 |
| PP | | | | | | | | | | | **.04** | **.0015** |
| T | | | | | | | | | | | .3 | .4 |

[a] OMP indicates open mouth condition; ACC, anteriorly closed condition; TRM, tongue-repositioning maneuver; SW, swallowing; PP, positive pressure; and T, test stage.

**Table 3.** Extended.

| Median Plateau Height (mbar) | | Duration of Plateaus (s) | | Area Under the Curve | |
|---|---|---|---|---|---|
| VS | SPS | VS | SPS | VS | SPS |
| 5.9 $\pm$ NA | | 11.5 $\pm$ NA | | 9.1 $\pm$ 14.9 | 14.2 $\pm$ 12.1 |
| 9.6 $\pm$ NA | 14.1 $\pm$ 13 | 14.5 $\pm$ NA | 14.7 $\pm$ 11.5 | 11.9 $\pm$ 13.5 | 33.5 $\pm$ 73.2 |
| 11.8 $\pm$ 8 | 37.9 $\pm$ 23 | 17 $\pm$ 2.8 | 20.8 $\pm$ 9.5 | 15.3 $\pm$ 25.7 | 96.6 $\pm$ 245.7 |
| | 9.8 $\pm$ 3.9 | | 18.6 $\pm$ 9.1 | 7.5 $\pm$ 7.6 | 25.8 $\pm$ 34.3 |
| 9.6 $\pm$ 4.6 | 7.7 $\pm$ 3 | 20.1 $\pm$ 2.5 | 13.9 $\pm$ 2.1 | 73.1 $\pm$ 61.1 | 67.9 $\pm$ 43.7 |
| 14.5 $\pm$ 7.5 | 17.3 $\pm$ 14.5 | 24 $\pm$ 12.8 | 24.3 $\pm$ 5.2 | 180.2 $\pm$ 199 | 219.8 $\pm$ 256.4 |
| 10.7 $\pm$ 4.5 | 19.6 $\pm$ 27.2 | 20.9 $\pm$ 9.6 | 19 $\pm$ 8.6 | 105.8 $\pm$ 137.9 | 256.2 $\pm$ 585.8 |
| 15.9 $\pm$ 9.5 | 12.3 $\pm$ 6.9 | 22.7 $\pm$ 6.2 | 21.8 $\pm$ 10.2 | 127.9 $\pm$ 198.4 | 179.7 $\pm$ 247.2 |
| 20.9 $\pm$ 17.6 | 34.7 $\pm$ 24.4 | 38.5 $\pm$ 17.6 | 35.4 $\pm$ 16.4 | 539 $\pm$ 483.3 | 871.8 $\pm$ 810.7 |
| 21.1 $\pm$ 11 | 29.4 $\pm$ 18.3 | 25 $\pm$ 14.4 | 22.1 $\pm$ 9.1 | 444.1 $\pm$ 387.8 | 637 $\pm$ 619.5 |
| 15.9 $\pm$ 9.1 | 18.4 $\pm$ 24.6 | 37.6 $\pm$ 16.2 | 28.1 $\pm$ 18.2 | 249 $\pm$ 304.5 | 342.1 $\pm$ 666.3 |
| 21.6 $\pm$ 21.3 | 31.1 $\pm$ 44.4 | 23.2 $\pm$ 9.3 | 28.6 $\pm$ 15.5 | 349.2 $\pm$ 592.1 | 678.2 $\pm$ 1285.8 |
| | | | | 45.1 $\pm$ 49.3 | 49.2 $\pm$ 45.3 |
| | | | | 57.4 $\pm$ 58.5 | 72.2 $\pm$ 88.2 |
| | | | | 34.9 $\pm$ 29 | 48.4 $\pm$ 59.5 |
| | | | | 48.8 $\pm$ 54.1 | 63.4 $\pm$ 95 |
| | | | | 0.2 $\pm$ 0.7 | 0.1 $\pm$ 0.2 |
| | | | | 6.7 $\pm$ 19.5 | 3.8 $\pm$ 6.3 |
| | | | | 1.3 $\pm$ 3.1 | 1.9 $\pm$ 3.7 |
| | | | | 3.3 $\pm$ 9.2 | 4.1 $\pm$ 13.8 |
| | | | | 0.9 $\pm$ 0.4 | 1.2 $\pm$ 0.7 |
| | | | | 1 $\pm$ 1.3 | 1 $\pm$ 1.3 |
| | | | | 0.7 $\pm$ 0.6 | 1.5 $\pm$ 3.1 |
| | | | | 1.6 $\pm$ 2.2 | 1.4 $\pm$ 2 |

sufficient numbers of untreated Angle Class II/1 adolescents or adults within the recruitment period who were also willing to participate in the study. In addition, the increased age range of group I subjects compared to those of the malocclusion groups may explain some of the results that were found to be characteristic in that group. Although there seems to be a controversy in the literature regarding whether there are[18,19] or are not[20] age-related changes in terms of lip and tongue pressuresor not, no reliable data seem to be available on potential age-related changes in intraoral compartment formation between preadolescents, adolescents, and adults. However, the swallowing pattern may be subject to change within this time period, and this needs to be considered as a possible limitation to the generalizability of our study findings.

With regard to the testing procedures, we omitted multiple testing corrections deliberately in order to avoid false negatives. This study aims at generating

**Table 5.** *P*-Values for Pairwise Comparisons of All Four Groups, Separated by Section, for Measurements at the Vestibular Space (VS) and Subpalatal Space (SPS). Only Those Sections That Have Been Identified as Being Significant in Global Comparisons Have Been Given (See Table 4). Bold Values Indicate Significance[a]

| | | Peaks | | Median Peak Height | | Plateaus | | Median Plateau Height | | Duration of Plateaus | | Area Under the Curve | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Section | Group | VS | SPS | VS | SPS | VS | SPS | VS | SPS | VS | SPS | VS | SPS |
| TRM | I vs II1 | .5 | .2 | .5 | .6 | .4 | .97 | .4 | .8 | .06 | .03 | .5 | .4 |
| TRM | I vs II2 | .2 | .3 | .2 | **.03** | .03 | .09 | .9 | .02 | .81 | .2 | **.02** | **.006** |
| TRM | I vs O | .3 | .5 | **.04** | .045 | .3 | .6 | .9 | .11 | **.0196** | .3 | .02 | .07 |
| TRM | II1 vs II2 | .17 | .07 | .06 | .3 | .06 | .2 | .3 | .049 | .09 | .7 | .18 | .2 |
| TRM | II1 vs O | .2 | .1 | **.02** | .3 | .2 | .8 | .5 | .1 | .95 | .3 | .28 | .6 |
| TRM | II2 vs O | .97 | 0.9 | .5 | .9 | .5 | .2 | .9 | .5 | **.038** | .7 | .7 | .4 |
| PP | I vs II1 | | | | | | | | | | | **.017** | **.001** |
| PP | I vs II2 | | | | | | | | | | | .14 | **.003** |
| PP | I vs O | | | | | | | | | | | **.01** | **.0003** |
| PP | II1 vs II2 | | | | | | | | | | | .3 | .5 |
| PP | II1 vs O | | | | | | | | | | | .9 | .8 |
| PP | II2 vs O | | | | | | | | | | | .3 | .9 |

[a] TRM indicates tongue-repositioning maneuver; PP, positive pressure; O, anterior open bite occlusion; and I, neutral occlusion (control).

**Table 6.** *P*-Values for Comparison of Measurements at the VS and SPS, Separately for Section and Group[a]

| Section | Group | Peaks (n) | Median Peak Height (mbar) | Plateaus (n) | Median Plateau Height (mbar) | Duration of Plateaus (s) | Area Under the Curve |
|---|---|---|---|---|---|---|---|
| OMP | I | .3 | .6 | .3 | | | .002 |
| OMP | II1 | .8 | .3 | .3 | .6 | .6 | .04 |
| OMP | II2 | .5 | .08 | .4 | .06 | .5 | .03 |
| OMP | O | .4 | .9 | .07 | | | .004 |
| ACC | I | .9 | .9 | .7 | .6 | .01 | .9 |
| ACC | II1 | .7 | .5 | .7 | .8 | .3 | .5 |
| ACC | II2 | .58 | .9 | .5 | .6 | .7 | .3 |
| ACC | O | .4 | .1 | .4 | .7 | .6 | .1 |
| TRM | I | .6 | .09 | .5 | .06 | .8 | .3 |
| TRM | II1 | .6 | .8 | .8 | .3 | .8 | .4 |
| TRM | II2 | .6 | .7 | . | .4 | .2 | .4 |
| TRM | O | .6 | .2 | .3 | .9 | .5 | .2 |
| SW | I | | | | | | .8 |
| SW | II1 | | | | | | .7 |
| SW | II2 | | | | | | .8 |
| SW | O | | | | | | .8 |
| PP | I | | | | | | .8 |
| PP | II1 | | | | | | .7 |
| PP | II2 | | | | | | .3 |
| PP | O | | | | | | .8 |
| T | I | | | | | | .05 |
| T | II1 | | | | | | .98 |
| T | II2 | | | | | | .96 |
| T | O | | | | | | .6 |

[a] OMP indicates open mouth condition; ACC, anteriorly closed condition; TRM, tongue-repositioning maneuver; SW, swallowing; PP, positive pressure; O, anterior open bite occlusion; and T, test stage.

a pool of important findings that might help us to design further studies. Thus, we accept false-positive findings, with which we can better cope (compared with false-negatives). Statistical testing was applied to achieve a ranking via *P*-values for a individual curve parameters and findings.

## Clinical Implications

Formation of intraoral negative pressure is essential for swallowing.[11,13] This study tried to address the question of how this pressure can be achieved in the presence of malocclusions that are typically accompanied by a tongue posture between the teeth rather than against the palate, such as in the case of anterior open bites or Angle Class II/1 malocclusions. The mean VS plateau durations of groups I and II2 were distinctively longer than those of groups O and II1. The fact that there were no significant differences in terms of negative SPS pressure formation between the different occlusion groups may be interpreted to

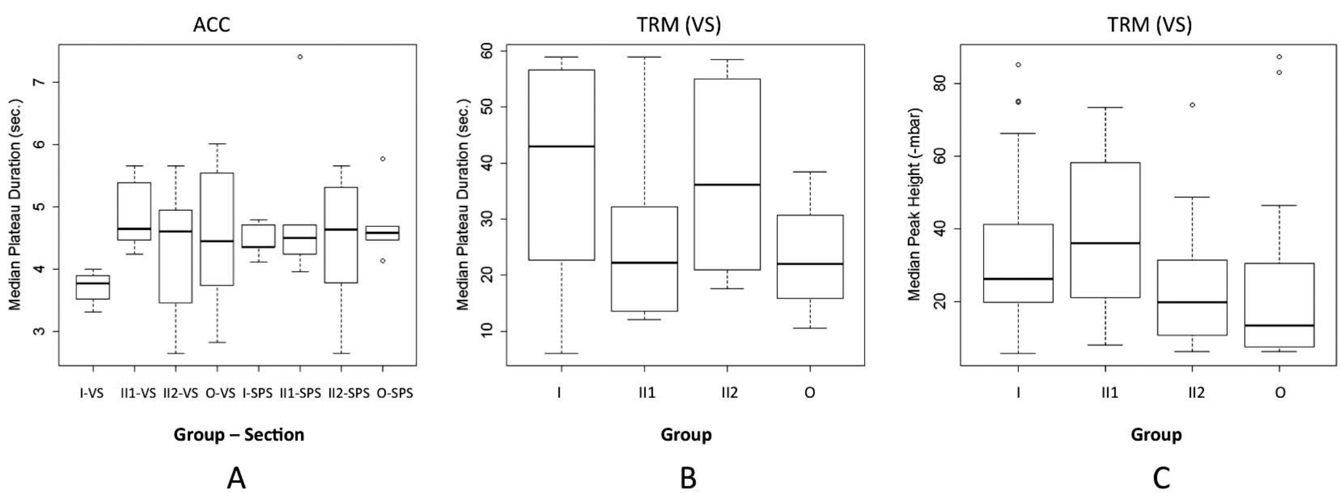


**Figure 2.** A–C. Distribution of median pressure plateau duration at the VS and SPS during ACC (A) and at the VS during TRM (B) and median peak heights at the VS during TRM (C).

represent the effect that occurs when subjects of groups O and II1 create a seal by pressing the margins of their tongues against their teeth during suction, potentially supported by an additional contraction of the buccinator against the teeth, in order to prevent an ingress of air between the teeth.[20,21] It is suggested that the development of a correct tongue-to-palate swallowing pattern may form and widen the dental arches during craniofacial development to suit the tongue, while persistence of a swallowing pattern that includes a pressing of the tongue between the teeth may not.[3] This would explain the triggering of the development and persistence of open bites and Angle Class II/1 malocclusions in some subjects and would be substantiated by our finding that subjects with the vertically or sagittally open incisor configurations in groups O and II1 seem to be unable to keep negative pressure levels at the VS for longer time periods. Therefore, our findings seem to support the point of view that a training of tongue postures may be a promising basis for the correction of malocclusions. Future research will address differences in compartment formation between low and high muscle tone groups. Intraoral pressure recordings are considered a useful diagnostic tool in the screening for the progression of such preorthodontic exercises.

## CONCLUSIONS

- The null hypothesis was rejected for mean VS plateau durations and peak heights and for SPS AUC.
- Nonopen dental configurations (groups I and II2) seem to enable longer negative pressure levels at the VS, in contrast to vertically or sagittally open incisor configurations (groups O and II1).

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