Received: 12 September 2018 | Revised: 18 October 2018 | Accepted: 24 October 2018

DOI: 10.1111/joor.12741

ORIGINAL ARTICLE

WILEY Journal of Oral Rehabilitation

Tongue pressure distribution of individual normal occlusions and exploration of related factors

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Funding information
National Natural Science Foundation of China, Grant/Award Number: 81670082

Summary

Background: Tongue plays an important part in oral and maxillofacial system. Measurement of tongue pressure helps to evaluate the performance of tongue movement.

Objectives: To establish a system for measuring tongue pressure against hard palate and to preliminarily explore pressure distribution of individual normal occlusions and the relationship with dental arch form.

Methods: A total of 19 volunteers of individual normal occlusions out of 189 dental students met inclusion criteria (nine males, ten females, aged 25.53 ± 0.96 years). A force-sensing resistor device was used to measure tongue pressure at rest and functional state (swallowing). We observed tongue pressure of four channel (anterior, posterior and lateral sides of hard palate) in sitting, supine position and swallowing. We analysed pressure differences according to gender and explored correlation relationship between tongue pressure and dental arch width and length using 3D digital maxillary image.

Results: In rest, tongue pressure against hard palate increased from front to back in both sitting and supine position, without gender differences. When swallowing saliva, the pressure at lateral sides of females was found significantly higher than that of males. Bivariate correlation analysis revealed duration of swallowing was positively correlated with BMI and weight at posterior region and positively correlated with palatal length at anterior palate. The greater the dental arch width, the smaller the pressure of swallowing in the anterior and lateral region.

Conclusion: In rest, there was consistent pressure of tongue against hard palate. The pressure increased significantly during swallowing, especially in females. Tongue pressure was related to dental arch length, width, BMI and weight.

KEYWORDS

dental arch form, gender, individual normal occlusion, swallow, tongue pressure, transducer

1 | INTRODUCTION

As an important part of the oral and maxillofacial system, tongue plays an important role in speech, mastication and swallowing reflex. It is even associated with diseases like dysphagia, obstructive sleep apnea and malocclusions as well. The measurement of tongue pressure helps to evaluate the performance of tongue in resting state and functional movement, which has been widely applied in clinical research—tongue pressure and masticatory function in dysphagia patients[1,2]; tongue pressure changes in patients with tongue cancer before and after resection and reconstruction[3]; tongue pressure in adults with Down syndrome[4]; tongue pressure of spinal and bulbar muscular atrophy patients,[5] etc.

In addition, uneven pressure from lip (cheek) and tongue and oral habits like tongue thrusting are key factors in the occurrence and development of malocclusion in many patients. Functional analysis

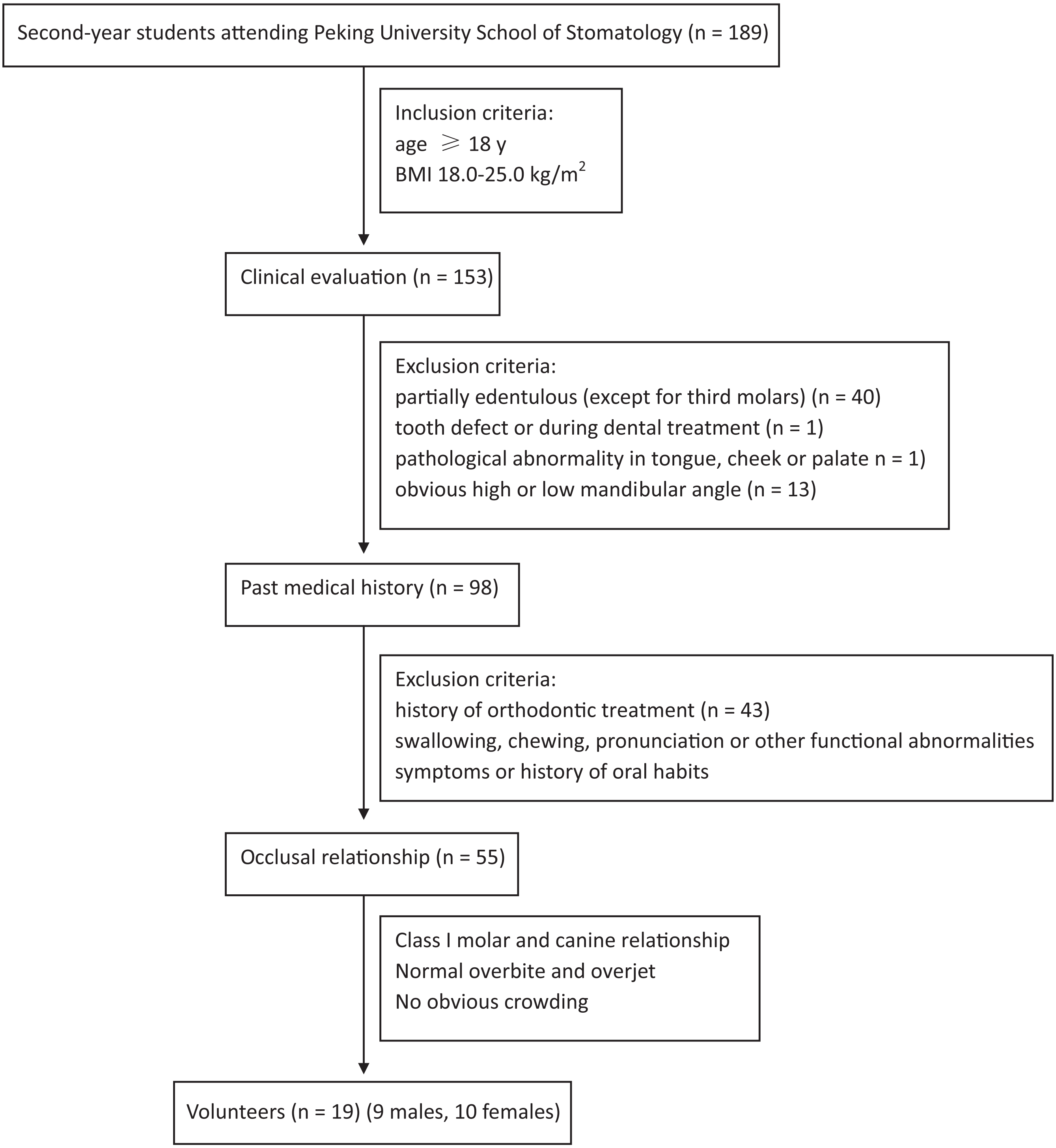

FIGURE 1 Screening process of individual normal occlusion volunteers

of tongue movement is also conducive to the establishment of orthodontic treatment plan and retention.

In prosthodontics, understanding the distribution of tongue pressure also helps to improve the retention and stability of dentures.[6,7]

Various studies of tongue pressure have been conducted. However, because of the anatomical conditions of oral cavity, measurement of tongue pressure when performing functional movements demands higher requirements for transducers. The transducers and methods used in previous studies varied greatly: type, shape, thickness and measurement regions, which resulted in the lack of comparability of different studies.

Based on previous studies, in this study, a tongue pressure measurement system was built with pressure sensors and matched data acquisition software to preliminarily observe the tongue pressure distribution of individual normal occlusions. And three-dimensional (3D) digital maxillary image was used to explore the relationship between tongue pressure and dental arch form.

2 | MATERIAL AND METHODS

2.1 | Subjects

This study recruited and screened volunteers from 189 second-year dental students who attended Peking University School of Stomatology. Inclusion criteria were as follows: age≥18 years; body mass index (BMI) between 18.0 and 25.0 kg/m^2; individual normal occlusion, no history of orthodontic treatment; no swallowing, chewing, pronunciation or other functional abnormalities; no symptoms or history of oral habits disturbance. Exclusion criteria were as follows: partially edentulous (except for the third molars); tooth defect or during dental treatment; pathological abnormality in tongue, cheek or palate; obvious high or low mandibular angle. The screening process is shown in Figure 1.

After screening, 19 volunteers with individual normal occlusions were recruited (nine males, 10 females, aged 25.53 ± 0.96 years).

The study was registered in Chinese Clinical Trial Registry (No. ChiCTR-COC-17013239). It was approved by committee of PKUSSIRB (No. 201631128) and written informed consent was obtained from all subjects.

2.2 | Soft occlusal pad

Maxillary impressions were routinely taken with alginate impression material, and plaster model cast was made. Individual vacuum-formed occlusal pad was made from plaster model with thin thermoplastic material (1.5 mm in thickness, Kombiplast soft D-420017, DreveDentamid GmbH, Unna, Germany) to fix transducers. The soft pad was trimmed by gingival margin in labial and buccal side but keep the pad on palate complete except for four measurement points. The four measurement points were (Figure 2): Ch.1 (anterior) was placed at incisive papilla, palatal side of contact area of maxillary central incisors; Ch.2(posterior) was placed at the intersection point of palatal vault and the last molars; Ch.3 and Ch.4(lateral) were placed at left and right palatal gingival margin of upper first molars, respectively. Recording wire of Ch.2, Ch.3 and Ch.4 leading to data acquisition handle was passed through the oral vestibule to minimise interference to inter-cusp occlusion and tongue movement.

FIGURE 2 Tongue pressure measurement channel on soft occlusal pad [Colour figure can be viewed at wileyonlinelibrary.com]

2.3 | Measurement of tongue pressure

A force-sensing resistor device (Flexiforce B201-L; Tekscan Inc., Boston, United States) with thickness of 0.203 mm was used. The sensor is 228.6 mm long and 14 mm wide, with sensing area of 9.53 mm in diameter. It is ultra-flexible so that it is comfortable in the mouth. The operating temperature is −40°C to 60°C and the force range is 0-111 N. Drift is lower than 5% per logarithmic time scale.

A load and force measurement system (Flexiforce ELF system; Tekscan, Inc., Boston, MA) was used for data acquisition. Real-time data capture could be displayed in strip chart and be output to data analysis software as ASCII.

Participants were asked to wear soft pad and sensors for 10 minutes to feel usual habitual tongue position and exercise swallowing naturally, as well as let sensors adapt to intra-oral temperature. They were asked to open their mouth for separation of tongue from palate to be calibrated as zero load. There were two positions for measurement: sitting position, with Frankfort plane parallel to horizontal plane; supine position, with Frankfort plane vertical to horizontal plane.

When in resting state, patients were instructed that "swallow saliva and then occlude gently, keep your tongue relaxed and put it in its usual position." The movement of swallowing saliva was instructed that "swallow saliva as usual as possible. Don't push too hard."

Measurement included resting pressure and pressure of swallowing saliva. With participants occluded in centric occlusion gently and breathed smoothly, 1 minute of resting pressure was recorded after output was stable. Swallowing pressure was measured three times with 1 minute interval.

All the original data were output as ASCII and verified with recorded video. Duration (tongue and palate from contact to separation), maximum pressure and average pressure of each sensor were analysed.

All the measurements were done and repeated 1 week later by the same researcher. Only when intra-class correlation coefficient (ICC) with results ≥0.75 could average be used in statistical analysis.

2.4 | Dental model analysis

A three-dimensional (3D) digital maxillary image was generated from the cast by a scanner (LPX-1200; Roland DG, Hamamatsu, Japan). Analysis of dental models was performed with reverse engineering software (Rapidform2006; INUS Technology Inc., Seoul, Korea).

The model measurements were as Figure S1A,B show. The staff who scanned, mixed and rearranged the sequence of dental models did not participate in data measurement. All the measurements were done and repeated one week later by the same researcher. Only when intra-class correlation coefficient (ICC) with results ≥0.75 could average be used in statistical analysis.

2.5 | Statistical analysis

The statistical analysis was performed using SPSS 21.0 (IBM Corp. IBM SPSS Statistics for Mac, Version 21.0. Armonk, NY). ICC of tongue pressure measurement was between 0.863 and 0.973 and ICC of dental cast analysis was between 0.973 and 0.981. Normal distribution of the variables was verified by the Shapiro-Wilk test. Descriptive analyses for normally distributed parameters were summarised as means and standard deviations. The intergroup differences in gender were performed by independent samples *t* test. One-way ANOVA was applied to compare different measurement points, and post hoc analysis of Bonferroni was used for multiple comparisons. Paired sample *t* test was applied to compare different measurement position (sit, supine) of the same volunteer. The relationship between tongue pressure and parameters of dental arch and demographic characteristics was determined using Pearson bivariate correlation analysis and two-tailed partial correlation analysis. Statistical significance was considered when $P < 0.05$.

3 | RESULTS

3.1 | Subjects

The general information of participants is shown in Table 1. A total of 19 volunteers with individual normal occlusions were recruited (nine males, 10 females, aged 25.53 ± 0.96 years). Height and weight of males were significantly higher than those of females, but there was no significant difference in BMI.

3.2 | Tongue pressure

Tongue pressure of each measurement point is shown in Figure 3A,B,C.

When the volunteers were in sitting and supine position, there was continuous tongue pressure against hard palate, which increased from front to back with individual difference. Pressure of Ch.1 decreased while pressure of posterior and lateral channels increased slightly from sitting to supine position. No significant difference was observed between different genders. (Figure 3A).

During swallowing, the maximum ($P = 0.005$) and average ($P = 0.010$) pressure of Ch.1 were significantly higher than Ch.2. Swallowing tongue pressure of females was higher than males and significant difference was found at Ch.3 and Ch.4. (Figure 3B).

When swallowing saliva, duration of Ch.3 and Ch.4 was longer than Ch.1 and then Ch.2, which was found significantly different in supine position. (Figure 3C).

3.3 | Correlation analysis

Pearson correlation analysis was used to explore the relationship between tongue pressure and parameters of dental arch and demographic characteristics. To further explore the relationship with dental arch form, partial correlation analysis was used with BMI controlled. The main results were that tongue pressure was correlated with dental arch width and that swallowing duration was correlated with weight, BMI and palatal length.

Ch.1 Maximum ($R^2 = -0.532$, $P = 0.028$) and average ($R^2 = -0.570$, $P = 0.017$) tongue pressure of swallowing saliva were negatively correlated with inter-first premolar width. When BMI was controlled, duration of swallowing saliva was correlated with palatal length ($R^2 = 0.513$, $P = 0.030$).

TABLE 1 Demographic data of 19 individual normal occlusion volunteers (M ± SD)

	All	Males	Females	*P*
N	19	9	10	-
Age(y)	25.53 ± 0.96	25.88 ± 0.99	25.27 ± 0.91	0.186
Height(m)	1.70 ± 0.09	1.76 ± .06	1.64 ± .06	0.000**
Weight(kg)	62.7 ± 12.2	70.5 ± 11.1	55.8 ± 8.7	0.006**
BMI(kg/m^2)	21.62 ± 3.00	22.61 ± 3.07	20.74 ± 2.78	0.307

**$P < 0.01$ independent sample *t* test between gender.

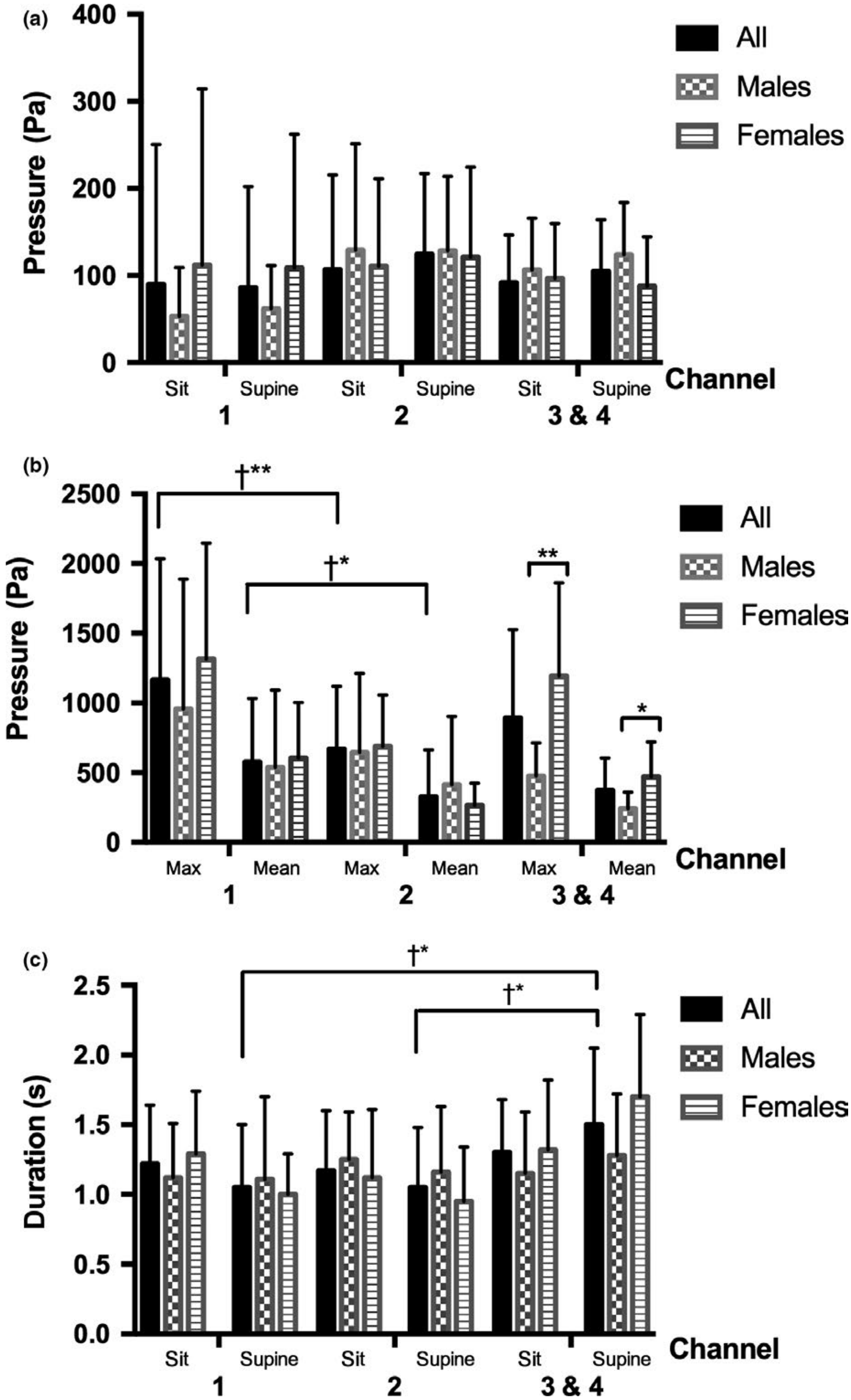

FIGURE 3 A, Rest pressure in sit and supine position. B, Maximum and average saliva swallowing tongue pressure **P* < 0.05 independent sample *t* test between gender ***P* < 0.01 independent sample *t* test between gender †**P* < 0.05 one-way ANOVA (post hoc analysis of Bonferroni) of different channel †***P* < 0.01 one-way ANOVA (post hoc analysis of Bonferroni) of different channel. C, Duration of tongue pressure of swallowing †**P* < 0.05 one-way ANOVA (post hoc analysis of Bonferroni) of different channel

Ch.2 Duration of swallowing saliva was positively correlated with BMI (R^2 = 0.629, *P* = 0.005) and weight (R^2 = 0.620, *P* = 0.004). When BMI was controlled, rest pressure in supine position was negatively correlated with posterior dental arch length (R^2 = −0.516, *P* = 0.041) and palatal length (R^2 = −0.521, *P* = 0.038).

Ch.3 and Ch.4 Resting pressure was positively correlated with height (R^2 = 0.243, *P* = 0.044). Maximum (R^2 = −0.624, *P* = 0.007) and average (R^2 = −0.508, *P* = 0.037) pressure of swallowing saliva were negatively correlated with inter-cuspid width. When BMI was controlled, correlation relationship was the same as above in swallowing pressure.

4 | DISCUSSION

4.1 | Sensors

For decades, researchers have conducted a continuous study of tongue pressure; however, there is no consistent understanding of measurement and correlation analysis, which is mainly due to different types of sensors. On one hand, the thickness of sensor has a great impact on the measurement,[8] which varied from 0.1 to 1.2 mm.[9,10] On the other hand, models of sensors in previous literature varied greatly as well: handheld pressure measurement devices[3,11-13] were easy to operate, while the stability of measurement position depended on the operator to a large extent. And it might interfere with functional movement of tongue.

Recently, sensor sheet[1,10,14] has been more commonly used. The sensor sheet contains multiple measurement points that work at the same time; however, the sizes of sensor sheet cannot precisely match the position of each patient's dental arch. In addition, the data acquisition system for collecting, amplifying and converting pressure signals is also customised, leading to lack of comparability of studies.

Sensors are considered to be key components of pressure measurement system. Inspired by sensor sheet, we used sensors with less thickness (including waterproof Mylar film), which had little influence on the measurement. Sensors were bonded to soft occlusal pad, which was easier made than palatal plate[15] and was more stable than attached with denture adhesive. The data acquisition handle of the sensor was easy to operate and individualised multi-point measurement could be carried out according to needs. The tongue pressure measurement system used in this study had good repeatability, with ICC between 0.863 and 0.973, and its output was relatively stable, so that each measurement had good consistency. It improved the comparability of data and can be applied to multidisciplinary quantitative research.

4.2 | Influence factors of tongue pressure

There are many influence factors of tongue pressure: age, gender, malocclusion, etc.

4.2.1 | Age

It was found that tongue pressure decreased with age.[16-18] Hara et al[19] have found that tongue pressure started to significantly decline in the 60s and 50s for men and women, which may further lead to age-related dysphagia. Thus, age-related decline may contribute more in elderly individuals.

4.2.2 | Gender

It was observed that anterior[16,18-22] and posterior[16,20] maximum tongue pressure of males exerted on hard palate were higher than females. However, no significant gender difference was found as well.[23-25] When considering tongue pressure during swallowing saliva, the findings were more inconsistent.[21,22,26] In our study, resting tongue pressure of different gender was not found different. But the maximum and average swallowing tongue pressure of females were significantly higher than males, especially at posterior measurement points. The difference between gender was consistent with Gingrich et al[11] had observed.

We found tongue pressure was mainly correlated with width growth and development. The inter-premolar, inter-molar and palatal width of male volunteers were significantly higher than those of females. This suggests that the morphology of the oro-facial system of females may result in the need for women to cope with greater tongue pressure to complete instructed swallowing.

4.2.3 | Weight and BMI

Our study found there was a positive correlation between duration of swallowing saliva at posterior tongue and weight as well as BMI, similar to the result of Fujita et al[27] and Ichikawa et al.[28] The former found better masticatory performance is directly associated with a higher BMI. And the latter found maximum tongue pressure was significantly correlated with body weight. There were differences in age, development stage and eating habits among different subjects. Relationship between tongue pressure and weight and BMI should be interpreted with caution.

4.2.4 | Malocclusions

Previous studies have found that there were three aspects of the relationship between malocclusion and tongue pressure. In sagittal direction, tongue pressure was related with craniofacial morphology. Maximum tongue pressure and swallowing tongue pressure were significantly lower in the skeletal class II group,[29] which might be caused by mandibular retrusion in class II patients. Lip closing force of skeletal class III patients was smaller than control group.[30] And after orthognathic surgery, patients were restored to class I facial type, and an increase of tongue pressure at molars was observed because of mandibular setback[31]and lip closing force increased as well.[30,32,33]

In horizontal direction, Takada et al[34] and Kieser et al[35] observed an asymmetry of buccal-lingual pressure in patients with facial asymmetry.

In vertical direction, tongue pressure with open bite was twice that of control group. And open bite subjects also exerted tongue pressure for a longer duration.[36]

Besides, a lower tongue pressure in the mouth-breathing group compared with nasal-breathing group was observed by Azevedo et al.[12] Breathing pattern impacts tongue pressure development and palatal morphology and mouth breathing negatively interferes in the development of stomatognathic structures.[37] Insufficient tongue strength in children can be early detected by the measurement of tongue pressure. Thus, preventive treatment could be carried out and quantitative evaluation of tongue position training results could be evaluated.

Most of the previous studies included patients with various degrees of malocclusion and analysed lip closing force and tongue pressure changes before and after certain treatment.[38-40] There were few researches focused on individual normal occlusions. The prevalence of normal occlusion relationships was rather low, about 7%-10.9%.[41,42] Fröhlich et al[43] analysed tongue pressure and its relationship with dental arch sizes of 20 participants with largely normal occlusions and found relatively few correlations between the pressures and the parameters describing the dental arch size.

A strict screening process was applied in our study and 19 individual normal occlusion volunteers were included. We also explored the relationship between tongue pressure distribution and dental arch sizes. The main results were that tongue pressure was negatively correlated with width and that duration was positively correlated with weight, BMI and dental arch length. But few correlations were found at anterior tongue, which may be related to insufficient sample size due to low prevalence of normal occlusions and good consistency among samples. Besides, the standard deviation of rest pressure at Ch.1 was rather high, we assumed it might be related with various habitual tongue position of the participants.

4.3 | Limitations

The craniofacial type and tooth inclinations of volunteers were not taken into consideration in this study. In the future, we need to expand the sample sizes to further explore other factors that may affect the tongue pressure.

5 | CONCLUSIONS

The measurement system of tongue pressure possesses good consistency to be used in future analysis. In rest, tongue pressure against hard palate increased from front to back. Anterior tongue pressure decreased while posterior tongue pressure increased slightly from sitting to supine position. The pressure increased significantly during swallowing, especially in females. Duration of swallowing was positively correlated with BMI and weight at posterior region and positively correlated with palatal length at anterior palate. The greater the dental arch width, the smaller the pressure of swallowing in the anterior and lateral region.

ACKNOWLEDGMENTS

The research was supported by National Natural Science Foundation of China No.81670082.

CONFLICT OF INTEREST

None.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Yu M, Gao X. Tongue pressure distribution of individual normal occlusions and exploration of related factors. *J Oral Rehabil*. 2019;46:249–256. https://doi.org/10.1111/joor.12741