

Lip Force in Healthy Young Adults: Reliability, Reference Values, and Associated Factors in a Cross-Sectional Study

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Abstract

Background

Lip force is an important component of oral function and has been used as an indicator of perioral muscle performance. Although lip force has been associated with oral functional conditions, factors influencing lip force in healthy young adults remain insufficiently understood. Furthermore, the reliability of lip force measurements is not fully established. Therefore, this study aimed to establish reference values for lip force, evaluate measurement reliability, and identify factors associated with lip force in healthy young adults.

Methods

This cross-sectional study included 100 healthy adults (40 men, 60 women; aged 20–35 years). Lip force was measured using a standardized button-pull method with a digital force gauge. Associations between lip force and sex, body size, occlusal characteristics, and occlusal force were assessed using Welch's t-test, Pearson's correlation analysis, and multiple linear regression analysis. Measurement reliability was evaluated using the intraclass correlation coefficient (ICC[2,1]) and Bland–Altman analysis.

Results

Mean lip force was 11.66 ± 3.74 N. Men exhibited significantly greater lip force than women (13.69 ± 3.98 N vs. 10.30 ± 2.89 N, $p < 0.001$; Cohen's $d = 1.01$). Lip force was positively correlated with height, body weight, and body mass index (BMI; all $p < 0.001$). No significant associations were observed between lip force and occlusal characteristics or occlusal force ($r = 0.01$, $p = 0.921$). Multiple linear regression analysis adjusted for age demonstrated that male sex ($\beta = 2.461$, $p = 0.002$) and BMI ($\beta = 0.596$, $p = 0.007$) were independently associated with greater lip force, whereas age and occlusal force were not. The button-pull method demonstrated good reliability, with an ICC(2,1) of 0.815. Bland–Altman analysis revealed a small fixed bias (-0.53 N) and no proportional bias.

Conclusions

Lip force in healthy young adults was associated with systemic physical characteristics, particularly sex and BMI, but not with occlusal characteristics or occlusal force. These findings suggest that lip force reflects perioral muscular function and overall physique rather than masticatory muscle performance. The standardized button-pull method demonstrated good reliability and may be useful for both clinical assessment and future research investigating oral muscular function.

1. Background

The lips play an important role in oral functions, including swallowing, speech production, mastication, and maintenance of oral posture. Adequate lip seal is important for normal oral function and craniofacial development, whereas impaired lip function has been associated with lip incompetence, mouth breathing, malocclusion, and reduced stability after orthodontic treatment [1–4]. Perioral muscle function has also been suggested to contribute to the equilibrium of forces acting on the dentition and may influence tooth position and facial morphology [3, 4].

Lip force, also referred to as lip-closing force or lip-seal strength, is used as an objective indicator of perioral muscle function. Quantitative assessment of lip force has attracted attention in orthodontics, prosthodontics, gerodontology, and oral rehabilitation because it provides a simple and non-invasive method for evaluating oral muscular function [5, 6]. Lip force measurements have also been used to assess oral functional status and to evaluate the effects of lip training and orofacial myofunctional therapy (MFT), particularly in children, older adults, and selected patient populations [7–10].

Evaluation of perioral muscle function is also important in adult orthodontics. Patients undergoing orthodontic or orthognathic treatment may exhibit long-standing perioral muscular dysfunction and oral habits associated with dentofacial deformities and malocclusion [11]. Therefore, postoperative MFT, which aims to re-train the function of the lips, tongue, and cheeks, may be important for improving the stability of occlusion after surgical orthodontic treatment [11, 12]. In this context, objective assessment of lip force may have clinical relevance in adult orthodontics and postoperative functional management. Among the available methods, the button-pull method is widely used because it is simple, inexpensive, and easy to apply in both clinical and research settings.

Lip force has been investigated in children, orthodontic patients, older adults, and individuals with impaired oral or neuromuscular function, and has been associated with oral function, dentofacial characteristics, and age-related decline in oral muscular function [1–10, 13–15]. However, reference data for lip force in healthy young adults remain limited. Most previous studies have focused on children, older adults, or specific patient populations, and relatively few studies have reported lip force data in healthy young adults [15]. To interpret lip force as a clinical or research outcome in adult orthodontics and adult MFT, it is first necessary to clarify the distribution of lip force in healthy young adults. In addition, the extent to which demographic, anthropometric, and oral functional factors, such as sex, body size, and occlusal force, are associated with lip force remains unclear.

When lip force is used as a clinical or research outcome, it is necessary to confirm the reliability of the measurements. Although previous studies have reported acceptable reproducibility of lip force measurements using the button-pull method or similar approaches [16, 17], few studies have evaluated the reliability of button-pull lip force measurements in healthy young adults [17–20]. This study aimed to provide reference data for lip force in healthy young adults, evaluate the reliability of lip force measurements obtained using a standardized button-pull method, and investigate the associations between lip force and demographic, anthropometric, and oral functional factors.

2. Methods

2.1 Study design and participants

This cross-sectional study included 100 healthy adult volunteers (40 men, 60 women; 20–35 years) recruited from medical staff and students at the Orthodontic Clinic, Institute of Science Tokyo. All participants were informed about the study and provided written informed consent. The study protocol was approved by the Institutional Research Ethics Committee (Approval No. S2025-002) and conducted in accordance with the Declaration of Helsinki. Participants currently undergoing orthodontic treatment were excluded from the study. Additional exclusion criteria included a history of maxillofacial trauma, surgery, or congenital anomalies affecting the perioral region, as well as the presence of temporomandibular disorders or impaired masticatory function.

2.2 Lip force measurement (button-pull method)

Lip force was measured using a standardized button-pull method. A circular button (25 mm in diameter) attached to a string was placed in the oral vestibule. A digital force gauge (PSM Push-Pull Scale; IMADA Co., Toyohashi, Japan) was used to record force values in N. Participants were seated upright in a chair without a backrest. The examiner held the force gauge so that the string was perpendicular to the participant's facial surface. Participants were instructed to maintain the button in position using lip pressure while the examiner applied a pulling force following a 3-second countdown. To ensure consistency, standardized verbal instructions were provided to all participants before each measurement, and no additional verbal instructions were given during the procedure. The maximum force recorded at the moment the button was dislodged was defined as the button-pull force. Measurements were performed four times with 10-seconds between measurements. To minimize the influence of outliers, the highest and lowest values were excluded, and the mean of the remaining two measurements was used for statistical analyses. All measurements were performed by a single examiner to minimize inter-examiner variability. The measurement procedure was based on previously reported button-pull methods for assessing lip-closing strength, with minor modifications for the present study population [16, 17].

2.3 Occlusal force measurement

Occlusal force was measured using pressure-sensitive film (Dental Prescale II; GC Corp., Tokyo, Japan). An appropriately sized film was selected and placed between the upper and lower dental arches. Participants were instructed to clench maximally in the intercuspal position for approximately 3 seconds while maintaining maximal force throughout the recording period. The pressure-sensitive film was analyzed using an occlusal force analyzing system (Bite Force Analyzer; GC Corp.) according to the manufacturer's instructions. Maximum occlusal force (N) was calculated automatically using the analysis software. Dental Prescale has been widely used for quantitative assessment of occlusal force and has been applied in studies investigating oral function and oral hypofunction [6, 21].

2.4 Assessment of variables

The variables evaluated in this study included sex, height, body weight, body mass index (BMI), overjet, overbite, upper and lower arch length discrepancy (ALD), and occlusal force. Height and body weight were measured at the time of examination, and BMI was calculated as body weight (kg) divided by height squared (m^2). Overjet and overbite were assessed during the clinical examination. Dental crowding was quantified using ALD, which was calculated separately for the maxillary and mandibular arches. Occlusal force was measured as described above.

2.5 Assessment of measurement reliability

The reliability of lip force measurements was evaluated using both relative and absolute reliability indices. Relative reliability was assessed using the intraclass correlation coefficient (ICC[2, 1]) based on a two-way random-effects model with absolute agreement. The first and second lip force measurements obtained from each participant were used for this analysis. The first and second measurements were selected to assess test–retest reliability before exclusion of extreme values and calculation of the final averaged lip force.

Absolute reliability and agreement between repeated measurements were assessed using Bland–Altman analysis. For each participant, the difference between the first and second measurements was calculated as the first measurement minus the second measurement, and this difference was plotted against the mean of the two measurements. The mean difference was defined as the measurement bias, and the 95% limits of agreement were calculated as the mean difference $\pm$ 1.96 standard deviations of the differences. Fixed bias was considered present when the 95% confidence interval (CI) of the mean difference did not include zero. Proportional bias was assessed by linear regression analysis of the measurement differences against the measurement means; a significant regression slope was interpreted as evidence of proportional bias.

2.6 Statistical analysis

All data are presented as mean $\pm$ standard deviation. Differences in lip force between males and females were evaluated using Welch's t-test. Associations between lip force and continuous variables, including height, body weight, BMI, overjet, overbite, upper and lower ALD, and occlusal force, were assessed using Pearson's correlation coefficient.

Multiple linear regression analysis was performed to identify factors independently associated with lip force. Lip force was entered as the dependent variable, whereas sex, age, BMI, and occlusal force were included as independent variables. Age was included in the model to account for potential confounding due to the observed sex difference in age. BMI was selected for inclusion in the multivariable model because it is a widely used indicator of body habitus that incorporates both height and body weight. Height and body weight were not simultaneously included in the model because of their collinearity with BMI. BMI was selected for inclusion in the multivariable model because it is a widely used indicator of body habitus that incorporates both height and body weight. Height and body weight were not simultaneously included in the model because of their collinearity with BMI. All statistical analyses were

performed using GraphPad Prism (GraphPad Software, Boston, MA, USA). A p-value < 0.05 was considered statistically significant.

A sample size calculation was performed for the primary association analysis between lip force and BMI. Assuming a moderate correlation coefficient of $r = 0.30$, a two-sided α level of 0.05, and 80% power, at least 84 participants were required. Therefore, the present sample size of 100 participants was considered sufficient for detecting a moderate association between lip force and body-size characteristics.

Because occlusal characteristics may influence lip force, the primary analyses were repeated as a sensitivity analysis in participants with near-normal occlusal characteristics, defined based on current occlusal findings as overjet and overbite between 1 and 4 mm and upper and lower ALD within ± 3 mm.

3. Results

3.1 Participant characteristics

A total of 100 healthy young adults (40 men, 60 women) were included in this study. Participant characteristics are summarized in Table 1. Men were significantly younger than women (24.32 ± 3.95 years vs. 25.83 ± 3.40 years, $p = 0.052$) and had significantly greater lip force values (13.69 ± 3.98 N vs. 10.30 ± 2.89 N, $p < 0.001$) and BMI (21.56 ± 1.75 kg/m² vs. 19.82 ± 1.40 kg/m², $p < 0.001$). No significant sex differences were observed in occlusal force, overjet, overbite, or upper arch length discrepancy. However, men exhibited more negative lower ALD values than women (-1.58 ± 1.68 mm vs. -0.89 ± 1.66 mm, $p = 0.047$).

3.2 Reliability of lip force measurement

The reliability of lip force measurements was assessed using the ICC and Bland–Altman analysis (Table 3, Fig. 3). The ICC[1, 2] for the first and second measurements was 0.814 (95% CI: 0.761–0.863), indicating good reliability. Bland–Altman analysis demonstrated a small fixed bias between repeated measurements, with a mean difference of -0.53 N. The lower and upper limits of agreement were -5.51 N and 4.45 N, respectively. No evidence of proportional bias was detected ($p = 0.416$).

3.3 Association between sex and lip force

Lip force was significantly greater in men than in women (Fig. 1). The magnitude of this difference was large, with a Cohen's d of 1.01 (Table 2).

3.4 Association between body size and lip force

Age was not significantly correlated with lip force ($r = -0.058$, $p = 0.568$). Significant positive correlations were observed between lip force and body size variables. Lip force was positively correlated with height

($r = 0.396$, $p < 0.001$), body weight ($r = 0.499$, $p < 0.001$), and BMI ($r = 0.429$, $p < 0.001$). Among these variables, body weight demonstrated the strongest correlation with lip force (Fig. 2, Table 2).

3.5 Association between occlusal characteristics and lip force

No significant associations were observed between lip force and occlusal characteristics, including overjet ($r = -0.071$, $p = 0.482$), overbite ($r = 0.014$, $p = 0.888$), upper ALD ($r = 0.028$, $p = 0.781$), and lower ALD ($r = 0.022$, $p = 0.830$) (Table 2).

3.6 Association between occlusal force and lip force

No significant association was observed between occlusal force and lip force ($r = 0.01$, $p = 0.921$) (Fig. 4). These findings suggest that lip force may represent an oral functional parameter distinct from occlusal force.

3.7 Multivariable analysis

Multiple linear regression analysis was performed to identify factors independently associated with lip force after adjustment for age (Table 4). Male sex (unstandardized $\beta = 2.461$, standardized $\beta: 0.324$, 95% CI: 0.914 to 4.009, $p = 0.002$) and BMI (unstandardized $\beta = 0.596$, standardized $\beta: 0.281$, 95% CI: 0.170 to 1.022, $p = 0.007$) were independently associated with greater lip force. In contrast, age (unstandardized $\beta = 0.059$, standardized $\beta: 0.058$, 95% CI: -0.125 to 0.242 , $p = 0.527$) and occlusal force, per 100-N increase (unstandardized $\beta = -0.025$, standardized $\beta: -0.029$, 95% CI: -0.177 to 0.127 , $p = 0.749$) were not significantly associated with lip force. The regression model explained 26.0% of the variance in lip force ($R^2 = 0.262$; adjusted $R^2 = 0.230$; overall model $p < 0.001$).

3.8 Sensitivity analysis

A sensitivity analysis restricted to participants with near-normal occlusal characteristics, defined as overjet and overbite between 1 and 4 mm and upper and lower ALD within ± 3 mm, yielded findings similar to those of the primary analysis ($n = 74$). In this subgroup, age was not significantly correlated with lip force ($r = -0.117$, $p = 0.321$), whereas BMI remained positively correlated with lip force ($r = 0.446$, $p < 0.001$). In the age-adjusted multivariable model, male sex (unstandardized $\beta = 2.055$, standardized $\beta = 0.272$, $p = 0.026$) and BMI (unstandardized $\beta = 0.671$, standardized $\beta = 0.327$, $p = 0.006$) remained independently associated with greater lip force, whereas age and occlusal force were not significantly associated with lip force (Additional File 1).

4. Discussion

The present study provides reference data for lip force in healthy young adults and clarifies factors that should be considered when interpreting lip force measurements in this population. The mean lip force observed in the present study was generally comparable to values reported in previous adult studies.

However, the main contribution of this study is not simply the reporting of mean lip force values. Rather, this study evaluated demographic, anthropometric, oral functional, and occlusal factors within the same well-defined sample of healthy young adults. Lip force was associated with sex and body size, particularly BMI, whereas it was not significantly associated with occlusal characteristics, including overjet, overbite, and arch length discrepancy, or with occlusal force. These findings suggest that, in healthy young adults, lip force may be influenced more strongly by systemic physical characteristics than by mild variations in occlusal morphology or occlusal force. Similar findings were observed in the sensitivity analysis restricted to participants with near-normal occlusal characteristics. In addition, the button-pull method demonstrated good intra-examiner reliability, supporting its usefulness as a simple clinical and research tool for assessing perioral muscle function.

4.1 Reference values and clinical relevance of lip force

A key contribution of the present study is the provision of reference data for lip force in healthy young adults. The mean lip force was 11.66 N in the overall study population, with higher values in men (13.69 N) than in women (10.30 N). These values were generally comparable to those reported in previous studies of healthy adults, supporting the external validity of the present findings [15].

These values may serve as practical reference data when interpreting lip force measurements in young adults, particularly in orthodontic patients with lip incompetence or in individuals undergoing orofacial MFT [7, 8, 15]. In clinical orthodontic practice, reduced lip force is often suspected in patients with lip incompetence, mouth breathing, or excessive overjet [1–4]. However, without reference data from healthy individuals in the same age range, it is difficult to determine whether a patient's lip force is meaningfully reduced or whether treatment has restored lip function to a level comparable to that of healthy adults.

The present findings may therefore provide a clinically relevant benchmark for future studies evaluating lip force before and after orthodontic treatment or MFT, including adult MFT. Nevertheless, these values should be interpreted as reference data rather than definitive diagnostic thresholds, because lip force may vary according to skeletal pattern, facial morphology, age, sex, body size, and measurement method.

4.2 Reliability of the button-pull method

The present study demonstrated good intra-examiner reliability of the button-pull method for measuring lip force, with an ICC of 0.815. According to established guidelines, ICCs greater than 0.75 indicate good reliability, supporting the reproducibility of the present measurement protocol [18]. Bland–Altman analysis revealed a small fixed bias between repeated measurements. Although a small mean difference (– 0.53 N) was detected, the wide 95% limits of agreement (– 5.51 to 4.45 N) indicate that the direction of error was not consistent at the individual level. The slightly higher values observed in the second measurement as a group average may be partly attributed to a learning effect or familiarization with the task in some participants. However, this magnitude of systematic error is minimal and unlikely to be

clinically meaningful. Furthermore, no proportional bias was detected, suggesting that measurement error did not increase as lip force values increased. Thus, measurement agreement was maintained across the observed range of lip force values [19, 20].

The button-pull method also offers practical advantages because it requires only a button, string, and force gauge and can be performed without specialized laboratory equipment. This simplicity facilitates clinical implementation and allows rapid assessment of perioral muscle function in a variety of settings. Taken together, these findings suggest that the button-pull method is a simple yet sufficiently reliable tool for assessing lip force in healthy young adults [16–18, 20].

4.3 Sex differences and association with body size

Men exhibited significantly greater lip force than women, with a large effect size. Although men and women differed significantly in age, age was included in the multivariable model to account for potential confounding. The associations of male sex and BMI with greater lip force remained significant after adjustment for age, whereas age itself was not significantly associated with lip force. These findings suggest that the observed associations of sex and BMI with lip force were not primarily explained by the age difference between male and female participants. This finding is consistent with previous reports demonstrating greater lip-seal strength in men than in women [15]. Sex differences in skeletal muscle strength are well established and are generally attributed to differences in muscle mass, muscle fiber size, and hormonal influences [22, 23]. Similar mechanisms may partly explain the greater lip force observed in male participants in the present study. Therefore, sex-specific reference values should be considered when interpreting lip force measurements in both clinical practice and future research.

Lip force was also positively associated with body size. Significant correlations were observed between lip force and height, body weight, and BMI, and BMI remained independently associated with lip force in the multivariable regression analysis. These findings suggest that lip force may be influenced not only by local perioral muscle function but also by general physical characteristics. This interpretation is consistent with previous studies showing that skeletal muscle strength and physical capability are closely related to body size and overall physical characteristics [24–27].

The association between BMI and lip force should be interpreted with caution. Minoura et al. reported an association between lip-seal strength and BMI among Japanese male workers; however, orthodontic and occlusal factors such as overjet, overbite, arch length discrepancy, and occlusal force were not evaluated in that study [14]. In contrast, the present study evaluated anthropometric and occlusal factors within the same population of healthy young adults. Because the BMI range in the present study was relatively narrow and body composition was not assessed, the observed association with BMI should not be interpreted as evidence that adiposity itself directly increases lip force. Rather, BMI may have functioned as a proxy for overall physique in this healthy young adult population. Taken together, these findings suggest that sex and body size should be considered when interpreting lip force measurements. The multivariable model explained 26.0% of the variance in lip force, indicating that a substantial proportion of individual variability remained unexplained. This unexplained variance may reflect factors not

assessed in the present study, such as skeletal pattern, lip morphology, facial soft tissue characteristics, orbicularis oris muscle function, neuromuscular control, oral habits, and participant effort during maximal lip closure. Thus, lip force should be regarded as a multifactorial functional measure that cannot be fully explained by sex, age, BMI, and occlusal force alone.

4.4 Occlusal characteristics and occlusal force

Contrary to our initial clinical expectation, lip force was not significantly associated with occlusal characteristics, including overjet, overbite, and upper or lower arch length discrepancy. Similar findings were observed in the sensitivity analysis restricted to participants with near-normal occlusal characteristics, suggesting that the present results were not substantially influenced by mild variations in occlusal characteristics.

Several explanations are possible. First, the present study included healthy young adults, and the distribution of occlusal characteristics was relatively narrow. Therefore, the study population may not have included enough individuals with severe malocclusion, marked lip incompetence, or excessive overjet to detect a relationship between lip force and occlusal morphology. Second, lip force may be influenced not only by dental alignment but also by skeletal pattern, lip morphology, facial soft tissue characteristics, and neuromuscular function. Thus, the absence of an association in this healthy population does not exclude the possibility that lip force may be reduced in patients with clinically significant malocclusion or lip incompetence.

Lip force also showed no significant association with occlusal force. Although both lip force and occlusal force are commonly regarded as indicators of oral function, they likely reflect different physiological domains. Occlusal force primarily reflects the functional capacity of the masticatory muscles, including the masseter and temporalis muscles, which are responsible for generating bite force [28, 29]. In contrast, lip force mainly reflects the activity of the orbicularis oris and other perioral muscles involved in lip closure and oral posture. Therefore, these two measurements evaluate distinct muscle groups and different aspects of oral function.

Kugimiya et al. reported a significant, albeit weak, association between lip-seal strength and occlusal force in community-dwelling adults [15]. In contrast, no such relationship was observed in the present study. This discrepancy may reflect differences in study populations. Whereas the present study included healthy young adults with relatively homogeneous oral functional status, Kugimiya et al. included adults across a wider age range, including older individuals, in whom age-related declines in oral function have been well documented [6, 14]. Greater variability in oral functional status may therefore have contributed to the association observed in their study. Differences in measurement methodologies may also have influenced the findings.

Taken together, these findings suggest that lip force should not be interpreted simply as a reflection of occlusal morphology or bite force. Rather, lip force appears to represent a distinct aspect of oral function, reflecting perioral muscle function while also being influenced by systemic physical

characteristics such as sex and body size. These findings may also be relevant when interpreting changes in lip force during adult MFT, including postoperative functional management after surgical orthodontic treatment, because demographic and anthropometric characteristics may influence lip force values independently of occlusal morphology.

4.5 Limitations

Several limitations should be acknowledged. First, this study included healthy young adults recruited from a single institution; therefore, the findings may not be generalizable to children, older adults, or patients with oral functional disorders, severe malocclusion, skeletal discrepancies, or marked lip incompetence. In addition, the cross-sectional design precludes conclusions regarding causal relationships between lip force and associated factors. Second, although overjet, overbite, and dental crowding were assessed, detailed skeletal, soft tissue, and body composition measures were not evaluated. Therefore, the mechanisms underlying the association between body size and lip force remain unclear. Because body composition was not assessed, it remains uncertain whether the observed association reflects skeletal muscle mass, fat mass, or overall body size.

The sex distribution was not balanced, and age differed between male and female participants. Although age was included in the multivariable model and was not significantly associated with lip force, residual confounding cannot be completely excluded. Finally, only intra-examiner reliability was evaluated; inter-examiner reliability should be examined in future studies to further establish the reproducibility and clinical applicability of the button-pull method.

Despite these limitations, the present study provides reference data for lip force in healthy young adults and demonstrates that lip force is associated with sex and body size but not with occlusal force or mild variations in occlusal characteristics. The present data may serve as a useful benchmark for interpreting lip force measurements in orthodontic practice and for future studies evaluating outcomes of orofacial myofunctional therapy.

5. Conclusions

This study provides reference data for lip force in healthy young adults and demonstrated that lip force could be measured with good reliability using a standardized button-pull method. Lip force was independently associated with sex and BMI, whereas no significant associations were observed with occlusal characteristics or occlusal force. These findings suggest that lip force reflects perioral muscle function and systemic physical characteristics rather than masticatory muscle performance or mild variations in occlusal morphology. The present data may serve as a useful reference for the assessment of lip force in clinical practice and future research.

Abbreviations

ALD: Arch length discrepancy

BMI: Body mass index

CI: Confidence interval

ICC: Intraclass correlation coefficient

MFT: Orofacial myofunctional therapy

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Institutional Research Ethics Committee of Institute of Science Tokyo (Approval No. S2025-002). Written informed consent was obtained from all participants prior to enrollment. All procedures were conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

MT conceived and designed the study, collected the data, performed the statistical analyses, interpreted the data, and drafted the manuscript. CK contributed substantially to study design, statistical analysis, data interpretation, and critical revision of the manuscript. KN, YK, and YY contributed to data collection and manuscript revision. TO supervised the study, contributed to study design and interpretation of the results, and critically revised the manuscript. All authors read and approved the final manuscript.

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Tables

Tables 1 to 4 are available in the supplementary files section

Figures

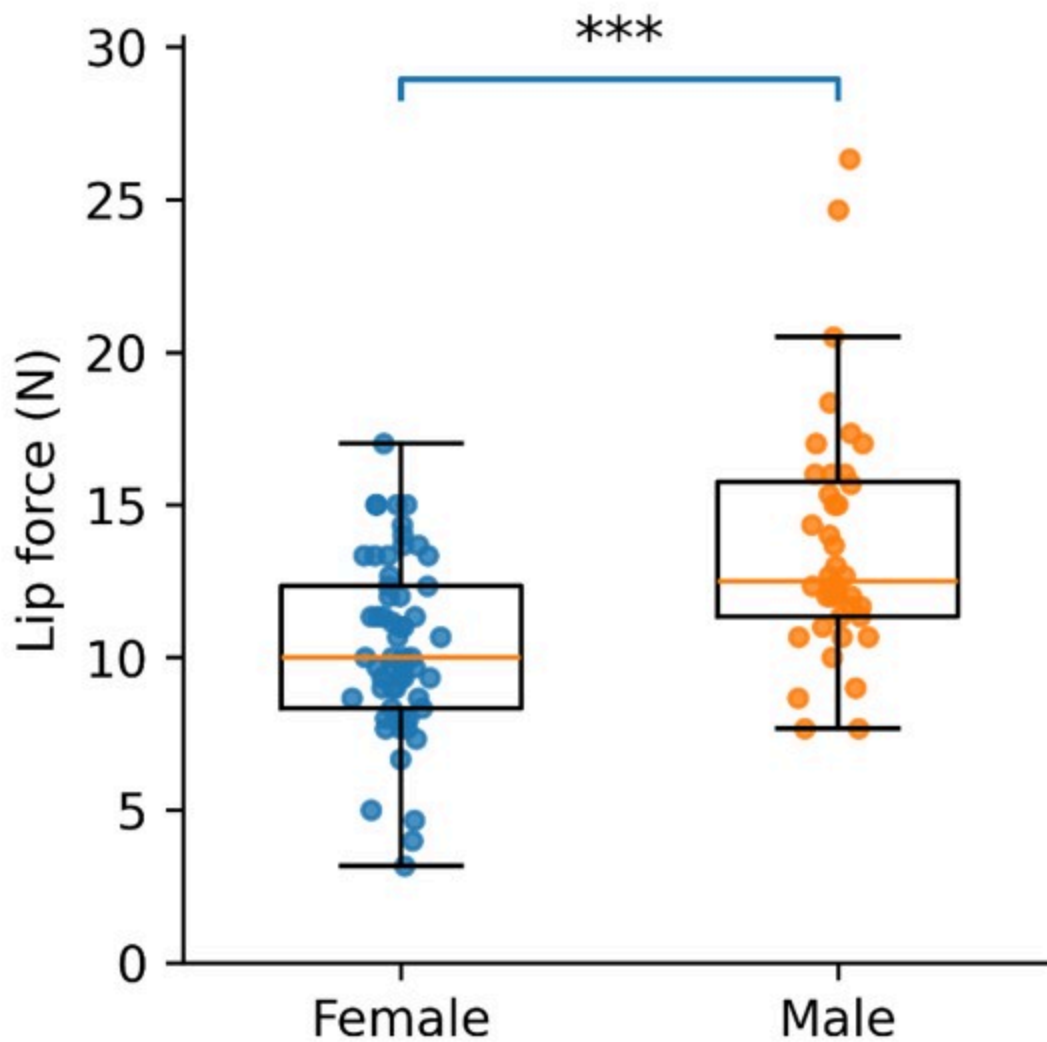


Figure 1

Comparison of lip force between men and women.

Box-and-whisker plots with individual data points are shown. The box represents the interquartile range (IQR), the horizontal line within the box indicates the median, and the whiskers represent 1.5 times the interquartile range, and individual points outside the whiskers are shown.***: $p < 0.001$ (Welch's t-test).

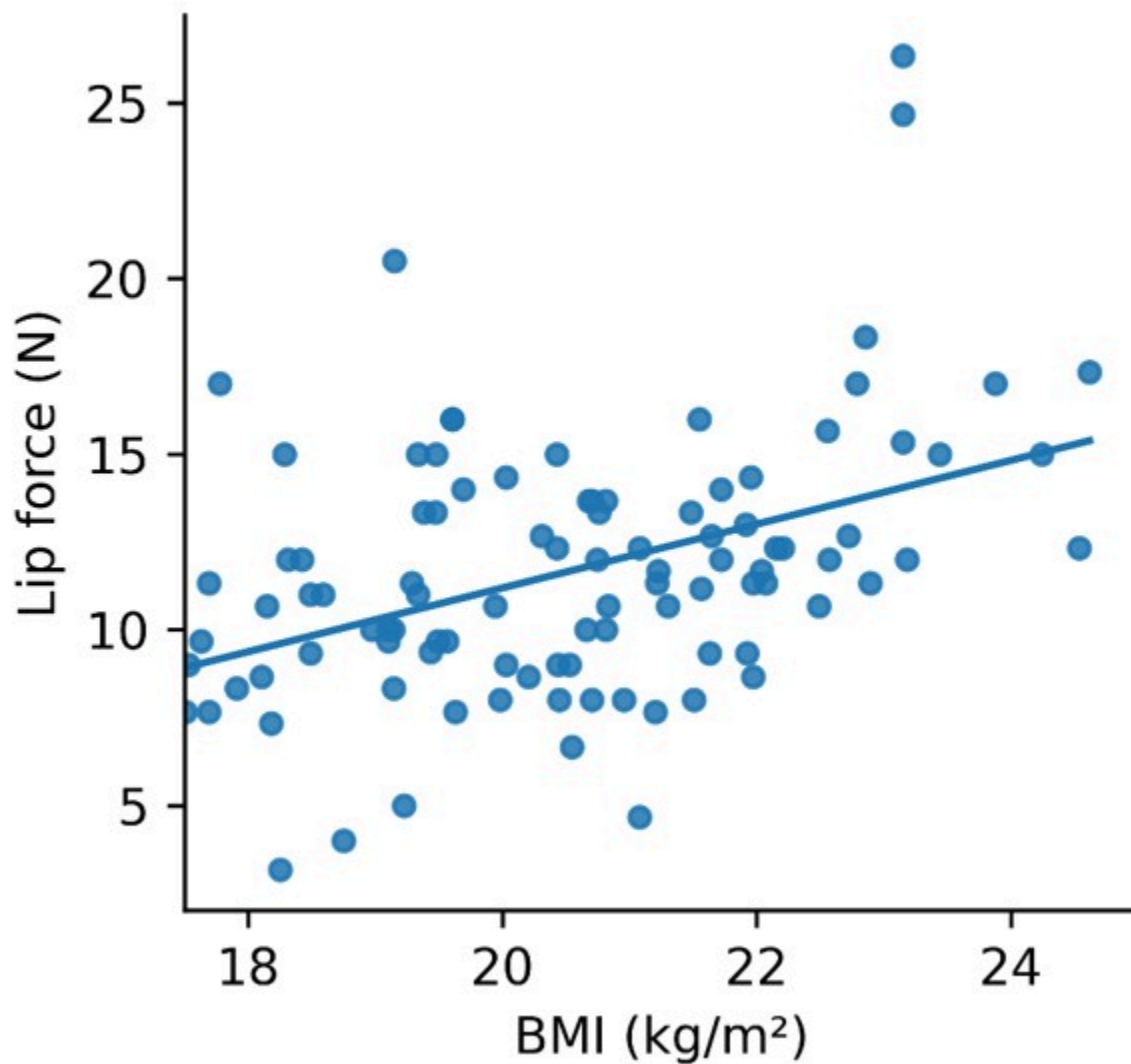


Figure 2

Association between body mass index (BMI) and lip force.

Scatter plot showing the relationship between BMI and lip force in healthy young adults. The solid line represents the linear regression line. Lip force was positively correlated with BMI ($r = 0.43, p < 0.001$), indicating that participants with greater BMI tended to exhibit higher lip force values.

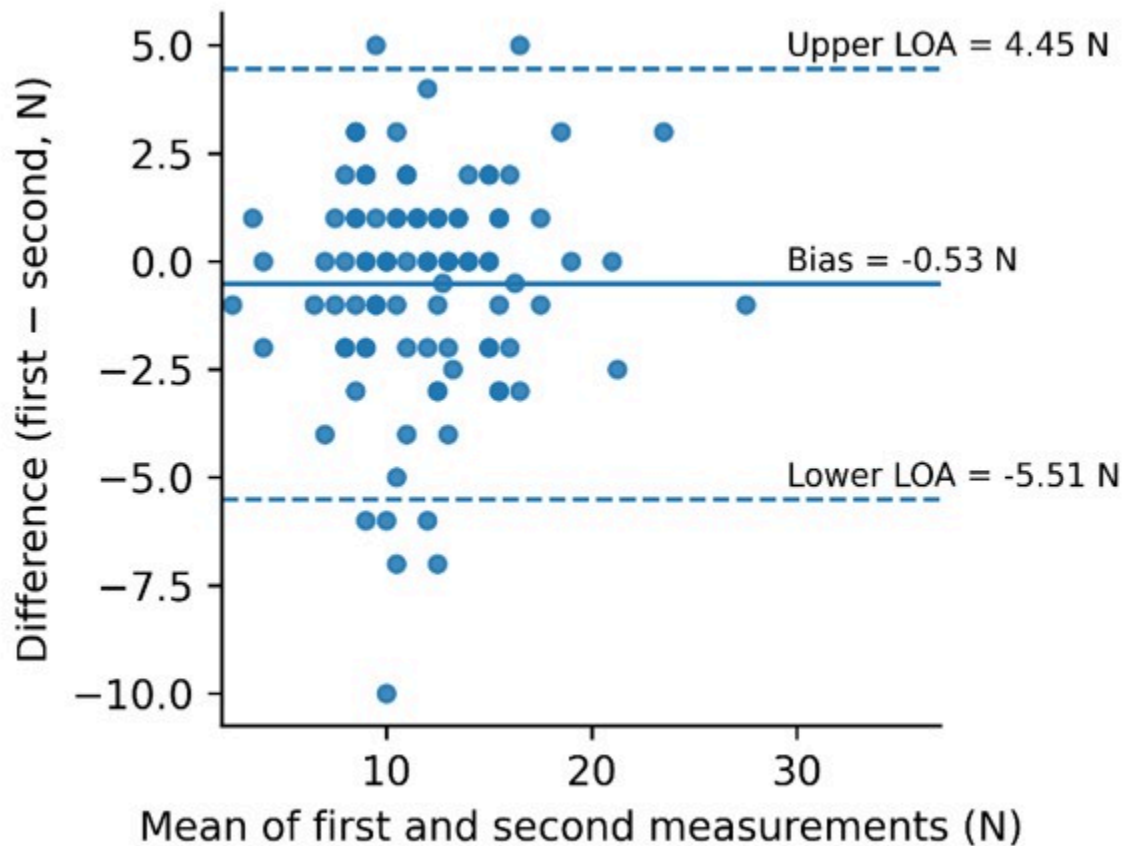


Figure 3

Bland–Altman analysis of repeated lip force measurements.

The difference between the first and second measurements is plotted against their mean. The solid horizontal line indicates the mean difference (bias = -0.53 N), and the dashed lines indicate the upper and lower 95% limits of agreement ($+4.45$ N and -5.51 N, respectively). No proportional bias was detected, indicating that measurement error did not increase across the range of lip force values.

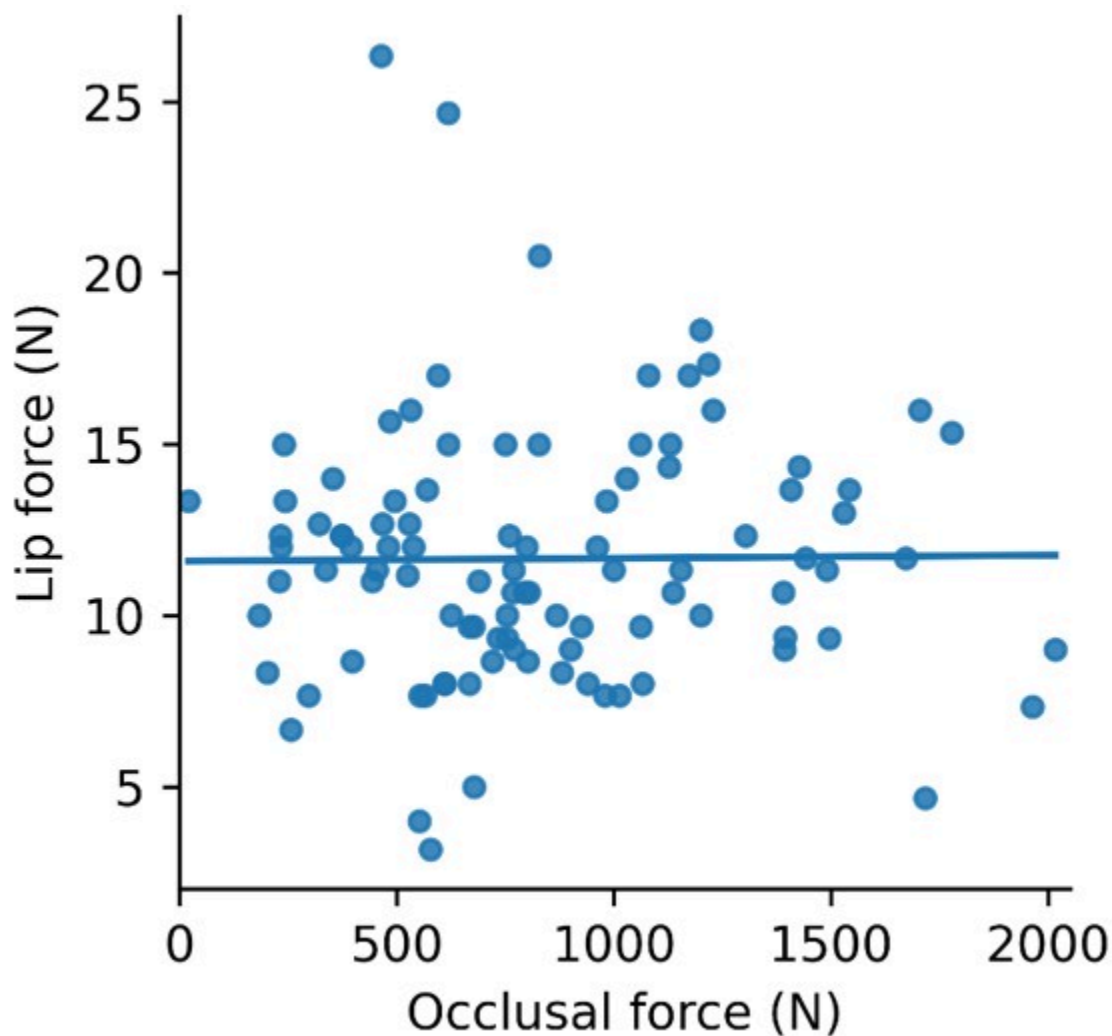


Figure 4

Association between occlusal force and lip force.

Scatter plot shows the relationship between occlusal force and lip force in healthy young adults. The solid line represents the linear regression line. No significant correlation was observed between occlusal force and lip force ($r = 0.01$, $p = 0.921$), suggesting that lip force and occlusal force represent distinct aspects of oral function.

Supplementary Files

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- [Additionalfile1.docx](#)
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