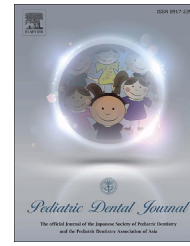
Available online at www.sciencedirect.com

Pediatric Dental Journal

journal homepage: www.elsevier.com/locate/pdj



Research Paper

The relationship between lip-closing strength and the related factors in a cross-sectional study

Issei Saitoh [a,*], Emi Inada [b], Yasutaka Kaihara [c], Yukiko Nogami [a], Daisuke Murakami [b], Norihito Ishitani [b], Tadashi Sawami [a], Yoko Iwase [a], Tsutomu Nakajima [a], Naoko Kubota [b], Kaoru Sakurai [c], Toshiya Tsujii [b], Yoshito Shirazawa [b], Mika Hanasaki [a], Mie Kurosawa [a], Miyuki Goto [d], Maki Nosou [c], Katsuyuki Kozai [c], Youichi Yamasaki [b], Haruaki Hayasaki [a]

[a] *Division of Pediatric Dentistry, Graduate School of Medical and Dental Science, Niigata University, 2-5274 Gakkocho-dori, Chuo-ku, Niigata 951-8514, Japan*
[b] *Department of Pediatric Dentistry, Kagoshima University Graduate School of Medical and Dental Sciences, 8-35-1 Sakuragaoka, Kagoshima 890-8544, Japan*
[c] *Department of Pediatric Dentistry, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8553, Japan*
[d] *Hiroshima University, 3-1-33 Shinonome, Minami-ku, Hiroshima 734-0022, Japan*

ARTICLE INFO

Article history:
Received 8 May 2017
Accepted 14 June 2017
Available online 17 July 2017

Keywords:
Children
Lip-closing strength
Developmental curve
Questionnaire

ABSTRACT

Introduction: No diagnostic standard for assessing lip-closing strength (LCS) currently exists for clinicians. The aim of this study is to examine patterns in age-related changes in LCS and factors associated with LCS.

Methods: In total, 554 children aged 3–12 years participated in this study. They had no serious dental caries and no lip or mandibular dysfunction. We measured the children's LCS with a force device, and their parents completed a 24-item questionnaire. Statistical analyses were performed using the unpaired *t*-test and Pearson's correlation coefficient test.

Findings: LCS increased significantly from 3 to 6 years of age, but reached a plateau phase from 7 to 12 years of age. Between the ages of 3–12 years, LCS rapidly increased until infancy in a similar trajectory to the general type observed in Scammon's growth curve. In the 3 to 6-year-old age group, the correlation coefficient between "Age" and LCS was higher than between other items, and "Gender" and "Drinking liquid during meals" moderately correlated with LCS in the 7 to 12-year-old age group. The acquisition of the daily habit of closing the lips during the daytime is very important among children. These results indicated that LCS in children might have two different stages, one is a period of development (3–6 years old) and the other is a stable period (7–12 years old).

Clinical Relevance: This device is useful clinically for measuring the LCS of both children and adults and for the understanding of oral function.

* *Corresponding author.*
E-mail address: isaito@dent.niigata-u.ac.jp (I. Saitoh).

http://dx.doi.org/10.1016/j.pdj.2017.06.002

1. Introduction

It is a well-known fact that continuous mouth breathing during the growing period is related to various etiological factors including not only oral dysfunction, malocclusion, a prevalence of bleeding gingivitis, detrimental oral environment and craniofacial growth, but also local inflammation, allergic rhinitis and obstructive sleep apnea syndrome [1–3]. Moreover, mouth breathing could affect cognitive working memory [4]. The increased prevalence of malocclusion represents a current trend attributed to the interaction of genetic and environmental factors. The analysis of factors related to the causes of these changes is essential for the planning of public health policies aimed at preventing and clinically intercepting malocclusion [5]. The acquisition of the daily habit of closing the lips during the daytime is very important among children.

Many researchers have reported on the importance of lip seal in the past. Based on the measurement of lip pressure among children 5–18 years of age, Newman et al. reported that lip pressure increased significantly in children between 5 and 14 years old according to their age regardless of gender [6]. Yoshida et al. have also reported having measured inferior-superior lip-closing strength (LCS) using LIP-DE-CUM® among 3 to 12-year-old children and demonstrated a close relationship between LCS and malocclusion [7]. On the other hand, Hagg et al. cited lip-muscle training in stroke patients with dysphagia, suggesting a close relationship between lip function and dysphagia [8].

Many different measurement systems for LCS and lip pressure have been developed over the past several decades. These have been roughly classified into three main types: 1) tension gauge type, 2) balloon type and 3) strain gauge type. The tension gauge type was constructed using the elasticity of a helical extension coiled spring. At first, Friel reported that he had developed three kinds of dynamometers to measure oral muscular pressure [9]. The balloon type was a measurement system which converted changes in balloon volume to air pressure. Feldstein [10], Kydd [11] and Hayashi [12] applied this system to practical lip and tongue function. Strain gauge type was mechanical sensor applied to measure the load-deformation relationship, which was reported to have been used by several studies [13,14].

These systems, however, were difficult to operate and use clinically, especially for measuring accurate values for children who were not able to follow complicated instructions. Repeated multiple measurements are often needed to monitor a patient's therapeutic process or to assess a child's development, but the optimal device using the same system is not always available. Unfortunately, each study uses a different device and method to measure LCS, and there is currently no diagnostic standard for its assessment by clinicians and researchers. During growth and development in children, institutional devices and methods are needed for the long-term monitoring of LCS. In this study, we did not use a clinical device authorized for LCS. The aim of this study is to examine the pattern of age-related changes in LCS as well as the factors associated with LCS.

2. Materials & methods

2.1. *Human subjects*

Participants in this study included 544 Japanese children in Kindergarten (Kagoshima, Japan) and elementary school (Hiroshima, Japan) (269 boys and 275 girls) and 19 adults (9 male and 10 female) (Table 1). They had no serious dental caries and no lip or mandibular dysfunction. This study was approved by the Ethics Committee of Niigata University Graduate School of Medical and Dental Sciences (approval number 26-R8-05-18), and informed consent was obtained from the subjects or their parents prior to their entering the study.

2.2. *Recording*

Subjects sat relaxed in a revolving chair with their eyes open. Natural head posture was adjusted so that their eye-ear plane was parallel to the floor. They were asked not to change their body position during the measurement (Fig. 1c). A Lippule button® (SHOFU Inc, Fig. 1b) was inserted into the space between their incisors and lips, and held with minimal mouth opening. They were asked to hold the button tightly in their mouths, and attached to the center of the button was a string 10–20 cm long. The other end of the string was attached to a Lippulekun®, which is a digital strain force gauge (SHOFU Inc, Fig. 1a). As the force gauge was pulled parallel to the floor, it recorded the highest tension before the button was pulled from the mouth. The recorded tension level indicated the LCS of the orbicularis oris. Before the measurements were taken, subjects were familiarized with the apparatus by making a few preliminary trials. Measurements were repeated three times.

2.3. *Questionnaires*

In order to determine factors associated with LCS, we asked the children's legal guardians to complete questionnaires. The questionnaires consisted of 24 questions, 10 of which were

Table 1 – Lip-Closing Strength (N) and inter- and intra-individual variation among the different button sizes.

	Button size	Inter-individual variation	Intra-individual variation
Male n = 21	Small	4.56	1.97
	Medium	8.12	1.70
	Large	15.19	8.23
Female n = 23	Small	3.15	1.37
	Medium	5.69	1.31
	Large	12.57	3.64
Boys n = 26	Small	2.59	0.81
	Medium	3.52	1.02
	Large	6.42	1.89
Girls n = 18	Small	1.29	0.55
	Medium	4.06	1.85
	Large	7.12	1.40

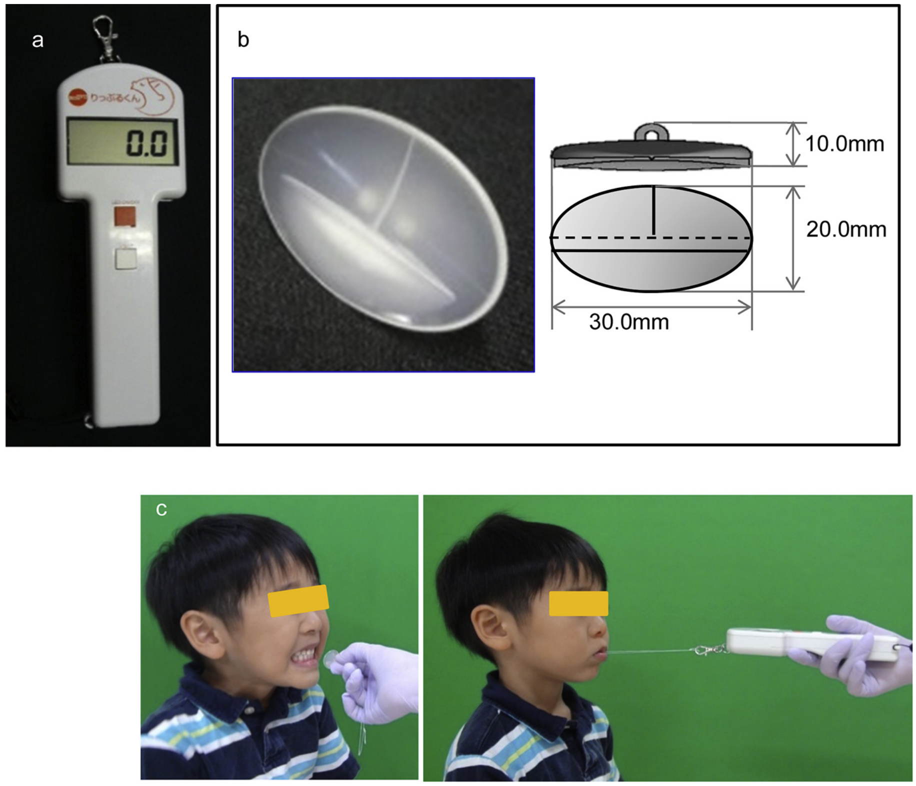


Fig. 1 – System of Lippulekun. a; digital force gauge (Lipplekun®). b; a button (Lipple-button®). c; A Button attached to the Lipplekun was inserted in the vestibule and pulled parallel to the floor.

related to the child's medical history of systematic disorders and 14 to lifestyle. Questions pertaining to histories of systematic disorders were based on a two-point scale (yes = 1; no = 0) and lifestyle-related questions were based on a four-point scale (no = 1; maybe no = 2; maybe yes = 3; yes = 4).

2.4. *Statistical analysis*

Multilevel linear statistical models [15,16] were used to evaluate any differences in LCS between ages and genders, using MLwiN® software (University of Bristol). Similar models have been previously applied to the analysis of chewing movement [17,18], mandibular excursions [19] and occlusal contact areas [20]. Multilevel linear models are composed of two parts: fixed and random. The fixed part estimates the population parameters, which closely correspond to the mean estimates of traditional analyses. The standard errors associated with each parameter were also estimated. The random part estimates variation at different hierarchical levels, with each level nested within the preceding level. A two-level model was used to estimate the mean and standard error of the mean (SEM) for significance. The two levels pertained to the random inter-individual (between the participants) and intra-individual (between trials) variations of LCS. Third or fourth order polynomials were used to separately model the age-related changes in LCS. The LCS values from 3 to 12 years old were calculated. Significance was set at $p < 0.05$.

To evaluate age-related differences in LCS values, we allocated the 12-year-old children to the control group, and we subsequently used Student's t-tests or Welch's t-tests (depending on equal or un-equal variance) to compare their results with those of the subjects aged 3–11 years as well as with those of the adults. Sex differences were examined for each age group using Student's t-test or Welch's *t*-test (depending on equal or un-equal variance). Levene's tests were performed to equality of variances. We conducted correlation analyses of the relationships between LCS and age, sex, and items from the questionnaire. The statistical analyses were performed using IBM SPSS Statistics for Windows (version 20; SPSS, Inc., Tokyo, Japan), and statistical significance was set at $P < 0.05$.

3. Results

Lippule buttons® are available in three sizes: small (width:10 mm), medium (width:15 mm) and large (width:20 mm). First we tested the most appropriate button sizes for the measurement of both children adults during preliminary research using multilevel linear models. Inter- and intra-individual variations in LCS according to the different sizes of buttons are shown in Table 1. The medium button was selected because it showed lower intra-individual variation and higher inter-individual variation.

The LCSs of, lip-closing strengths of, or LCS values/measurements for ages 3–12 and adults are shown in Table 2 and Fig. 2. The LCS values for boys aged 3 to 6 and girls aged 3–7 years were significantly lower in comparison to those of the

Table 2 – Lip-Closing Strength (N) in children.

Age	n	mean	SD	SE of difference	p-value
Males					
3	21	3.67	1.37	0.30	0.000**
4	27	4.99	2.87	0.55	0.000**
5	25	6.74	2.41	0.48	0.001**
6	22	7.67	3.01	0.64	0.018*
7	30	10.07	3.67	0.67	0.823
8	30	9.80	3.38	0.62	0.627
9	37	9.30	3.81	0.63	0.346
10	23	9.08	3.80	0.79	0.300
11	34	8.50	2.73	0.47	0.075
12	20	10.31	3.88	0.87	–
Adults	9	14.23	2.78	0.93	0.016*
Females					
3	19	3.50	1.56	0.36	0.000**
4	31	4.82	1.55	0.28	0.000**
5	20	6.08	1.73	0.39	0.000**
6	26	7.27	2.28	0.45	0.012*
7	32	7.47	2.31	0.41	0.015*
8	28	8.51	3.42	0.65	0.396
9	31	7.95	3.00	0.54	0.114
10	22	7.11	3.22	0.69	0.026*
11	45	9.04	3.42	0.51	0.747
12	21	9.32	3.04	0.66	–
Adults	10	12.56	1.94	0.62	0.036*

SD: Standard deviation.
SE: Standard Error.
p-values were calculated using Student's t-test or Welch's t-test.
Significant difference between each age group and the control group (12-year-old children).
*: p < 0.05, **: p < 0.01.

12-year-old children. Sex-related differences among these results were observed in the 7-year-old children. Adults displayed significantly higher LCS values in comparison to the 12-year-old children of both genders. Children of both sexes aged 3–6 years had significantly lower LCS values in comparison to the 12-year-old children. Adults displayed significantly stronger LCS in comparison to the 12-year-old children of both genders.

A multilevel model of the developmental curve of LCS is shown in Fig. 3, along with Scammon's growth curves. During the 3 to 12-year-old period, LCS rapidly increased until infancy in a similar trajectory to the general type observed in Scammon's growth curve.

Based on our analyses of LCS measurements, we conducted correlation analyses by dividing the subjects into two groups: children aged 3–6 years old (Age 3–6 group) and children aged 7–12 years old (Age 7–12 group). For the univariate regression analysis, Pearson's correlation coefficient test was performed. In the Age 3–6 group, the correlation coefficient between "Age" and LCS was higher than among the other items (Table 3-a). In addition, statistical comparisons in the Age 3–6 group indicated significant correlations between LCS and 6 items ("History of asthma", "Catches a cold easily", "Has a high fever frequently", "Often gets swollen tonsils", "Dryness of lips" and "Chews food well"). On the other hand, "Gender" and "Drinks liquid during meals" only moderately correlated with LCS in the Age 7–12 group (Table 3-b).

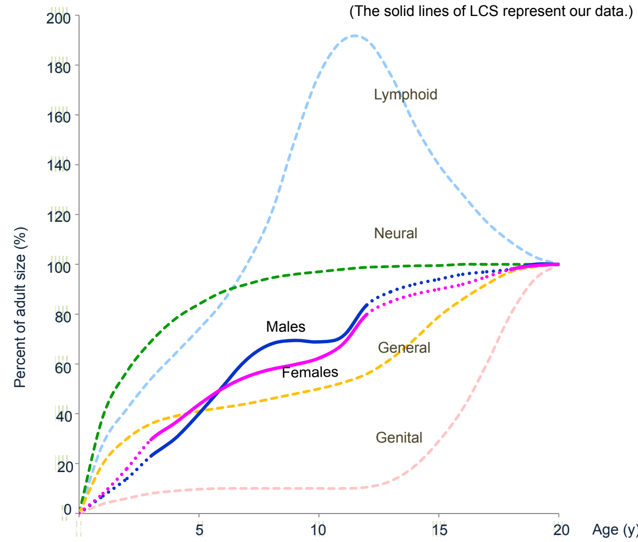


Fig. 3 – Scammon's growth curves and development curves of LCS.

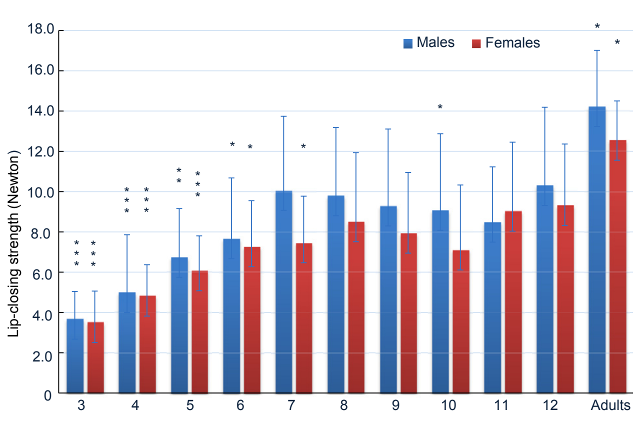


Fig. 2 – LCS of each age group and the difference from 12 years-old.

Table 3-a – Association between Lip-Closing Strength and items. (3–6 years-old).

Age 3–6 group	n	Peason's correlation coefficient (two-sided test)	p-value
Gender	213	0.052	0.451
Age	192	0.543	0.000***
History of asthma	174	−0.159	0.036*
Catch a cold easily	175	−0.236	0.002**
Have a high fever frequently	175	−0.168	0.026*
Often get swollen tonsils	170	0.186	0.015*
Dryness of lips	173	0.156	0.040*
Drink liquid during meals	175	0.011	0.882
Chews food well	175	0.163	0.032*

p-values were calculated using Student's t-test.
*p < 0.05, * *p < 0.01, ***p < 0.001.

Table 3-b – Association between lip-closing strength and items. (7–12 years-old).

Age 7–12 group	n	Peason's correlation coefficient (two-sided test)	p-value
Gender	361	0.176	0.001**
Age	353	0.036	0.497
History of asthma	353	0.005	0.919
Catch a cold easily	353	0.000	0.996
Have a high fever frequently	356	0.011	0.843
Often get swollen tonsils	331	−0.094	0.089
Dryness of lips	348	−0.027	0.621
Drink liquid during meals	355	0.206	0.000***
Chews food well	356	0.084	0.112

p-values were calculated using Student's t-test.
* *p < 0.01, ***p < 0.001.

4. Discussion

The lips have multiple functions and play a role in mastication, swallowing and speech, but they are also related to dental arch form [21], [22]. Weak force generated by perioral musculature is known to be a potent factor that can affect tooth position and malocclusion [21]. This force plays a role in guiding tooth eruption and maintaining dental arch form and stability. The lips, cheeks and tongue are the most important environmental determinants of tooth position and eruption [23].

The Lipple-button for measuring LCS in this system is constituted by an elliptical body 30.0 mm in width designed to coincide with the lingual morphology of the upper and lower lips. The tooth side of the button has a 20.0 mm horizontal chase corresponding to the subject's overjet, which enables a child to easily hold the button in his/her mouth. We examined three different sizes of Lipple-button (small, medium and large). Table 1 shows that inter- and intra-individual variation indicates the reproducibility of this system. The larger Lippule button size had the highest intra-individual variations in males and females, indicating lower reproducibility. While the small and medium sizes had almost the same reproducibility, the medium size was preferable due to higher inter-individual variation, which indicated various individual characteristics. Generally, adults had the tendency to show higher inter-individual variation than children [24]. Because the development of lip function in children could be assessed using this system, it might be useful for the measurement of LCS in both children and adults. On the other hand, the LCS values in this study were higher than those of Japanese preschool children measured by Fukami et al., in 2008 [25], and those of Japanese school children measured by Shiono et al. in 2015 [26]. The previous systems for the assessment of LCS used buttons with a similar shape, but the Lipple-button was developed to be easy to insert into the vestibule of a patient's mouth. Uniform buttons like the Lipple-button present several advantages because they allow unlimited usage by clinicians and researchers, they are suitable for various types of patients, and they enable the assessment of development from children to adults.

Regarding children's growth and development, we compared our analyses/with Scammon's growth curve (by Scammon). The differences in these curves for lymphoid, neural, general body and genital tissues can be considered the result of the hormonal changes that accompany sexual maturation and somatic growth in their functional capacity. This indicates that LCS rapidly increased until infancy in a similar trajectory to the general type observed in Scammon's growth curve. Subsequently, the general curve slowed down during the period between 3 and 11 years old and then resumed rapid growth during adolescence, which resulted in an "S"-shaped growth curve. These findings suggested that LCS rapidly increased between the ages of 3 and 6 years, and reached a plateau between the ages of 7 and 12 years. In contrast, LCS values among adults were significantly higher than those of 12-year-old children. Further investigation is needed to clarify the development of LCS after 13 years of age.

Correlations between LCS and the questionnaire data are shown in Tables 3-a and b. The Age 3–6 group had a significantly higher correlation to "Age" according to Pearson's correlation analysis. We found smaller correlation coefficients with "History of asthma", "Catches a cold easily", "Has a high fever frequently", "Often gets swollen tonsils", "Dryness of lips" and "Chews food well". On the other hand, the Age 7–12 group was related to "Gender" and "Drinks liquid during meals" but not "Age". We suggest that "Age" is an important factor affecting LCS during the 3 to 6-year-old period [7]. We consider it important that healthy growth and development is fostered especially among 3 to 6-year-old children, since we found a relationship between the development of LCS and advancing age in that group, but not in the Age 7–12 group (Figs. 2 and 3). On the other hand, physical growth and the establishment of healthy dietary habits were important factors among 7 to 12-year-old children, since "Gender" and "Drinks liquid during meals" were related to LCS in that group. Food particles and saliva are molded into a bolus at the oral phase of swallowing and forced to the back of the oral cavity. Therefore, pressure is necessary to swallow the bolus with a lip seal.

5. Conclusion and clinical relevance

The acquisition of the daily habit of closing the lips during the daytime is very important among children. These results indicated that LCS in children might have two different stages, one is a period of development (3–6 years old) and the other is a stable period (7–12 years old). This strain measurement device could be useful clinically for measuring the LCS of both children and adults and for the understanding of oral function.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

This work was supported by KAKENHI from Japan society for the Promotion of Science (No. 25463193), Japan.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards (institutional review board approval: 26-R8-05-18).

Informed consent

Informed consent was obtained from all individual participants included in the study.

REFERENCES

[1] Kasparaviciene K, Sidlauskas A, Zasciurinskiene E, et al. The prevalence of malocclusion and oral habits among 5-7-year-old children. Med Sci Monit 2014;20:2036–42. http://dx.doi.org/10.12659/MSM.890885.
[2] Gross AM, Kellum GD, Franz D, et al. A longitudinal evaluation of open mouth posture and maxillary arch width in children. Angle Orthod 1994;64:419–24. http://dx.doi.org/10.1043/0003-3219(1994)064<0419:ALEOOM>2.0.CO;2.
[3] Luzzi V, Ierardo G, Viscogliosi A, et al. Allergic rhinitis as a possible risk factor for malocclusion: a case-control study in children. Int J Paediatr Dent 2013;23:274–8. http://dx.doi.org/10.1111/ipd.12003.
[4] Kuroishi RC, Garcia RB, Valera FC, et al. Deficits in working memory, reading comprehension and arithmetic skills in children with mouth breathing syndrome: analytical cross-sectional study. Sao Paulo Med J 2015;133:78–83. http://dx.doi.org/10.1590/1516-3180.2013.7630011.
[5] Moimaz SA, Garbin AJ, Lima AM, et al. Longitudinal study of habits leading to malocclusion development in childhood. BMC Oral Health 2014;14:96. http://dx.doi.org/10.1186/1472-6831-14-96.
[6] Newman DG, Barnes A, Newman J. A study of bilabial lip pressure in a normal population. Aust Orthod J 1983;8:51–5.
[7] Yoshida Y, Otsuka A, Sakai S, et al. The force of lip closure in children (1) the relationship between the force of lip closure and age. Jpn J Pediatr Dent 2004;42:436–40.
[8] Hagg M, Anniko M. Lip muscle training in stroke patients with dysphagia. Acta Otolaryngol 2008;128:1027–33. http://dx.doi.org/10.1080/00016480701813814.
[9] Friel BA. An investigation into the relation of function and form. Br Dent J 1926;7:353–79.
[10] Feldstein L. An instrument for measuring muscular forces acting on the teeth. Am J Orthod 1950;36:856–9.
[11] Kydd WL. Maximum forces exerted on the dentition by the perioral and lingual musculature. J Am Dent Assoc 1957;55:646–51.
[12] Hayashi R, Tsuga K, Hosokawa R, et al. A novel handy probe for tongue pressure measurement. Int J Prosthodont 2002;15:385–8.
[13] Alderisio JP, Lahr R. An electronic technic for recording the myodynamic forces of the lip, cheek, and tongue. J Dent Res 1953;32:548–53.
[14] Shellhart WC, Moawad MI, Paterson RL, et al. Lip adaptation to simulated dental arch expansion. Part 1: reliability and precision of two lip pressure measurement mechanisms. Angle Orthod 1996;66:249–54. http://dx.doi.org/10.1043/0003-3219(1996)066<0249:LATSDA>2.3.CO;2.
[15] Strenio JF, Wisberg HI, Bryk AS. Empirical bayes estimation of individual growth curve parameters and their relationship to covariates. Biometrics 1983;39:71–86.
[16] Goldstein H. Multilevel mixed linear model analysis using iterative generalized least squares. Biometrika 1986;73:43–56.
[17] Throckmorton GS, Ellis 3rd E, Hayasaki H. Masticatory motion after surgical or nonsurgical treatment for unilateral fractures of the mandibular condylar process. J Oral Maxillofac Surg 2004;62:127–38.
[18] Kubota N, Hayasaki H, Saitoh I, et al. Jaw motion during gum chewing in children with primary dentition. Cranio 2010;28:18–29.
[19] Saitoh I, Tokutomi J, Hayasaki H, et al. Correlations between incisor and condyle motion during protrusion in children with primary dentition. Cranio 2007;25:90–7. http://dx.doi.org/10.1179/crn.2007.015.
[20] Okamoto A, Hayasaki H, Nishijima N, et al. Occlusal contacts during lateral excursions in children with primary dentition. J Dent Res 2000;79:1890–5.
[21] Jung MH, Yang WS, Nahm DS. Effects of upper lip closing force on craniofacial structures. Am J Orthod Dentofac Orthop 2003;123:58–63. http://dx.doi.org/10.1067/mod.2003.54.
[22] Keim RG. Tooth movement through directed tongue and lip pressure. Gen Dent 1994;42:61–4.
[23] Di Fazio D, Lombardo L, Gracco A, et al. Lip pressure at rest and during function in 2 groups of patients with different occlusions. Am J Orthod Dentofac Orthop 2011;139:e1–6. http://dx.doi.org/10.1016/j.ajodo.2010.02.030.
[24] Saitoh I, Tokutomi J, Hayasaki H, et al. Correlations between incisor and condylar movements during lateral excursion in children with primary dentition. J Oral Rehabil 2007;34:800–6. http://dx.doi.org/10.1111/j.1365-2842.2006.01715.x.
[25] Fukami A, Saitoh I, Inada E, et al. A reproducibility method to test lip-closing strength in preschool children. Cranio 2010;28:232–7. http://dx.doi.org/10.1179/crn.2010.032.
[26] Shiono Y, Morikawa K, Maki K. Comparative clinical study evaluating lip-closure forces in association with tongue pressure in children. Ped Dent J 2015;25:19–25.